State of California
The Resources Agency
Department of Water Resources
Bay-Delta Office

METHODOLOGY FOR FLOW AND SALINITY ESTIMATES IN THE SACRAMENTO-SAN JOAQUIN DELTA AND SUISUN MARSH

TWENTY-FIFTH ANNUAL PROGRESS REPORT TO THE STATE WATER RESOURCES CONTROL BOARD
In Accordance with Water Right Decision 1485, Order 9

October 2004

Arnold Schwarzenegger	**Mike Chrisman**	**Lester Snow**
Governor	Secretary for Resources	Director
State of California	The Resources Agency	Department of Water Resources

FOREWORD

This is the twenty-fifth annual progress report of the California Department of Water Resources' San Francisco Bay-Delta Evaluation Program, which is carried out by the Delta Modeling Section.

It documents progress in the development and enhancement of the Bay-Delta Office's Delta Modeling Section's and Division of Environmental Service's Suisun Marsh Planning Section's computer models and reports the latest findings of studies conducted as part of the program. This report was compiled by Michael Mierzwa, with assistance from Jane Schafer-Kramer and Patricia Cornelius, under the direction of Bob Suits, Senior Engineer, and Tara Smith, program manager for the Bay-Delta Evaluation Program.

On-line versions of previous annual progress reports are available at:

http://modeling.water.ca.gov/branch/reports.html

For more information contact:

Tara Smith
tara@water.ca.gov
(916) 653-9885

-or-

Michael Mierzwa
mmierzwa@water.ca.gov
(916) 653-9794

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1 Introduction

Over the last eleven years, the Bay-Delta Office's Delta Modeling Section and Division of Environmental Services' Suisun Marsh Planning Section have been developing and enhancing the Delta Simulation Model 2 (DSM2), the tools used to support DSM2 modeling, and other Delta flow and salinity estimation tools. The following are brief summaries of work that was conducted during the past year. The names of contributing authors are in parentheses.

Chapter 2 – REALM Update

Last year's annual progress report introduced development of a new multi-dimensional decision-support system for modeling in the Delta. The Delta Modeling Section has initiated contracts with several outside parties for technical assistance and has already tested prototype 2D flow and transport solvers. This chapter discusses both the work that has been completed in the past year and addresses funding scenarios and future deliverables.
(Eli Ateljevich and Ralph Finch)

Chapter 3 – DSM2 Geometry Investigations

The most recent DSM2-HYDRO and QUAL recalibration was described in the 2001 annual report. Since that time the U.S. Geological Survey (USGS) has collected 10-minute flow data at six locations surrounding Franks Tract. The DSM2 geometry around Franks Tract was modified in an effort to investigate sensitivities in DSM2's ability to simulate flow and EC around Franks Tract. This chapter describes the work performed in this series of geometry investigations.
(*Bob Suits and Jim Wilde*)

Chapter 4 – Modeling DO & Temperature in DSM2 Planning Studies

The boundary conditions necessary to simulate dissolved oxygen (DO) and water temperature in a standard DSM2 16-year planning study were developed as part of DWR's Integrated Storage Investigations's In-Delta Storage (ISI-IDS) project. Missing data consisting of DO, temperature, and climate data from 1974 – 1991 were generated with surrogate data from 1997 – 2001. The remaining water quality parameters necessary to model DO and water temperature were based on various samples taken from the Delta. This chapter summarizes the methods used to develop all of these boundary conditions.
(*Hari Rajbhandari*)

Chapter 5 – Calculating Net Delta Outflow Using CALSIM II and DSM2

CALSIM II input is frequently used as the input in DSM2 planning studies, thus leading to frequent comparisons between CALSIM and DSM2 Net Delta Outflow (NDO) estimates. However, Net Delta Outflow is difficult to physically measure in the Delta and the simple mass balance techniques used to calculate CALSIM NDO do not exactly match the NDO estimated by DSM2 at Martinez. This chapter explains why different methods of calculating NDO result in different flow estimates while outlining several common techniques that can be used to accurately estimate NDO in CALSIM and DSM2.
(*Jamie Anderson*)

Chapter 6 – Net Delta Outflow Computations for DSM2 Steady State Simulations

Chapter 6 makes use of the Net Delta Outflow computation techniques presented in Chapter 5, but focuses on using these techniques to address the accuracy of DSM2 in simulating steady state conditions (i.e. conserving mass) and simulating gradual transitions between steady state conditions. Steady state conditions are tested for three downstream tidal forcing conditions: a constant stage, a 25-hour 19-year repeating tide, and an adjusted astronomical tide. All three conditions are useful in explaining some of the basic flow and stage patterns that occur in the Delta.
(*Jamie Anderson*)

Chapter 7 – Extensions and Improvements to DSM2

Work on the DSM2 database was first reported in the 2002 annual report. This new version of DSM2, DSM2-DB, has since been expanded to include additional new improvements. The features discussed in this chapter include the graphical users interface (GUI), new treatment of gates in DSM2, trigger and action based operating rules, the HDF5 data storage format, and parallel processing. All of these new DSM2 extensions are available only to the DSM2-DB. DSM2-DB is currently undergoing testing.
(*Ralph Finch, Eli Ateljevich, Edward Diamond, and Tawnly Pranger*)

Chapter 8 – Real-Time Data and Forecasting Proof of Concept and Development

The Department has been using DSM2 to produce short-term water quality and south Delta water level forecasts since 2001. Recently, the Department's Municipal Water Quality Investigations (MWQI) program has organized a Real-Time Data and Forecasting (RTDF) committee composed of DWR and water contractors to investigate improving the Department's current DSM2 short-term Delta water quality forecasts and extending these forecasts down the California Aqueduct. This chapter describes the background behind the RTDF committee and the Section's work with that committee, focusing on a DSM2-Aqueduct seasonal forecast model proof of concept and the development tasks associated with building both short-term and long-term models capable of addressing the needs of MWQI and the water contractors.
(*Michael Mierzwa and Bob Suits*)

Chapter 9 – Using QUAL Fingerprinting Results to Develop DOC Constraints in CALSIM

The concept of fingerprinting using DSM2 was introduced in the 2002 annual report. Since that time, DSM2 fingerprinting studies have been used to help develop dissolved organic carbon constraints for use in CALSIM in support of DWR's Integrated Storage Investigations's In-Delta Storage (ISI-IDS) project. The CALSIM organic carbon constraints were developed by using DSM2 to establish a relationship between volume of releases and various flow parameters. This chapter discusses the basic methodology used to develop volume - flow relationships using volumetric fingerprinting results for use in any study by using the ISI-IDS project as an example.
(*Michael Mierzwa and Jim Wilde*)

Chapter 10 – Development of Tidal Analysis Routines

Chapter 10 introduces a tidal analysis post-processing tool developed by DWR's Division of Environmental Services Suisun Marsh Section that calculates tidal datum parameters and the phase difference between stage and tidal current. Though this tool is currently available for post-processing RMA model results, this chapter focuses on the methodology used by the tidal analysis routines to calculate the tidal datum parameters. This same methodology can be extended to the analysis of either field data or other model results as well.
(*Brad Tom*)

Chapter 11 – Website and DSM2 Users Group

The Delta Modeling Section introduces two of its newest outreach efforts: a newly redesigned webpage and a DSM2 Users Group. The redesigned Section webpage follows a standard format adopted by the Department of Water Resources allowing easy navigation. A DSM2 Users Group was formed to meet the increasing demand for DSM2 support by bringing various DSM2 users together to discuss both current DSM2 work and future model / study needs. The DSM2 Users Group makes use of the new webpage by hosting a new bulletin board where questions and answers from all uses are publicly posted and archived.
(*Min Yu*)

Chapter 12 – Calculating Clifton Court Forebay Inflow

The State Water Project's Clifton Court Forebay inflow is controlled by a series of five radial gates. The flow entering the forebay through these gates is not directly measured. In 1988 equations were developed to estimate the flow through each gate based on stage differences inside and outside of the forebay. The 1988 equations are useful in estimating historical flow through the individual forebay gates. This chapter describes these inflow equations and then compares them with another technique used by DWR's Delta Field Division to estimate the inflow through the gates.
(Kate Le)

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

25th Annual Progress Report
October 2004

Chapter 2:
REALM Update

Author: Eli Ateljevich and Ralph Finch

2 REALM Update

2.1 Introduction

The River, Estuary, and Land Model (REALM) project was introduced in last year's Annual Report (Ateljevich and Finch, 2003). The goal of REALM is to create a public model that offers performance and decision-making support that is not currently available in models. DWR's Delta Modeling Section believes that the technologies brought to the project by key partners will allow development of a model with capabilities that would otherwise be difficult to achieve.

2.2 Features

REALM will have features typical of current models, including 1-, 2-, and eventually 3D hydrodynamics, water quality transport, and particle tracking. The model will also include features necessary to solve important Bay/Delta questions, such as tidal or seasonal wetting and drying of areas, non-conservative constituents, wind effects, and particle tracking behavior.

To improve numerical accuracy and speed, REALM will use the computational infrastructure developed by Lawrence Berkeley National Laboratory (LBNL), one of our two key collaborators. REALM will use parallel processing, Adaptive Mesh Refinement (AMR), and embedded boundaries to improve accuracy and to concentrate computational effort in regions that are numerically difficult (for instance, with steep gradients) or pertinent to a study. These features are described in Ateljevich and Finch (2003).

REALM will also include systems analysis to make decision support, policy analysis, and real-time Delta management easier. REALM will provide:

❑ Model Steering: operating rules for boundary conditions and hydraulic devices that are managed adaptively (e.g. gates or pumps that are opened or closed depending on the state of the Delta such as water quality or stage values).

❑ Optimal control and data assimilation methods to make real-time control for O&M more accurate.

❑ Multi-objective analysis and visualization to let users see the tradeoffs between competing objectives, such as stage, exports, and water quality.

❑ Geographical Information System (GIS) for data storage and visualization.

The first release of REALM will have only a subset of all the features it is expected to eventually have. Feature priority will be driven by real-world problems and computational issues (see Section 2.5).

2.3 Status

In the past year, REALM has moved from a purely conceptual stage to the beginning stages of a working project. DWR staff worked on REALM in consultation with Lawrence Berkeley National Labratory (LBNL) and developed prototype 2D flow and transport solvers. These were applied to simplified test problems but the solver has yet to be applied to Delta geometry. Figure 2.1 illustrates the use of one of the LBNL computational techniques, AMR. This feature calculates the required grid density on-the-fly throughout the problem area by increasing the density where additional grid points are needed to maintain accuracy, and decreasing the density where possible to lessen computational demand. Other LBNL features available are embedded boundaries (allowing accurate description of natural boundaries in rectangular grids) and parallelization libraries.
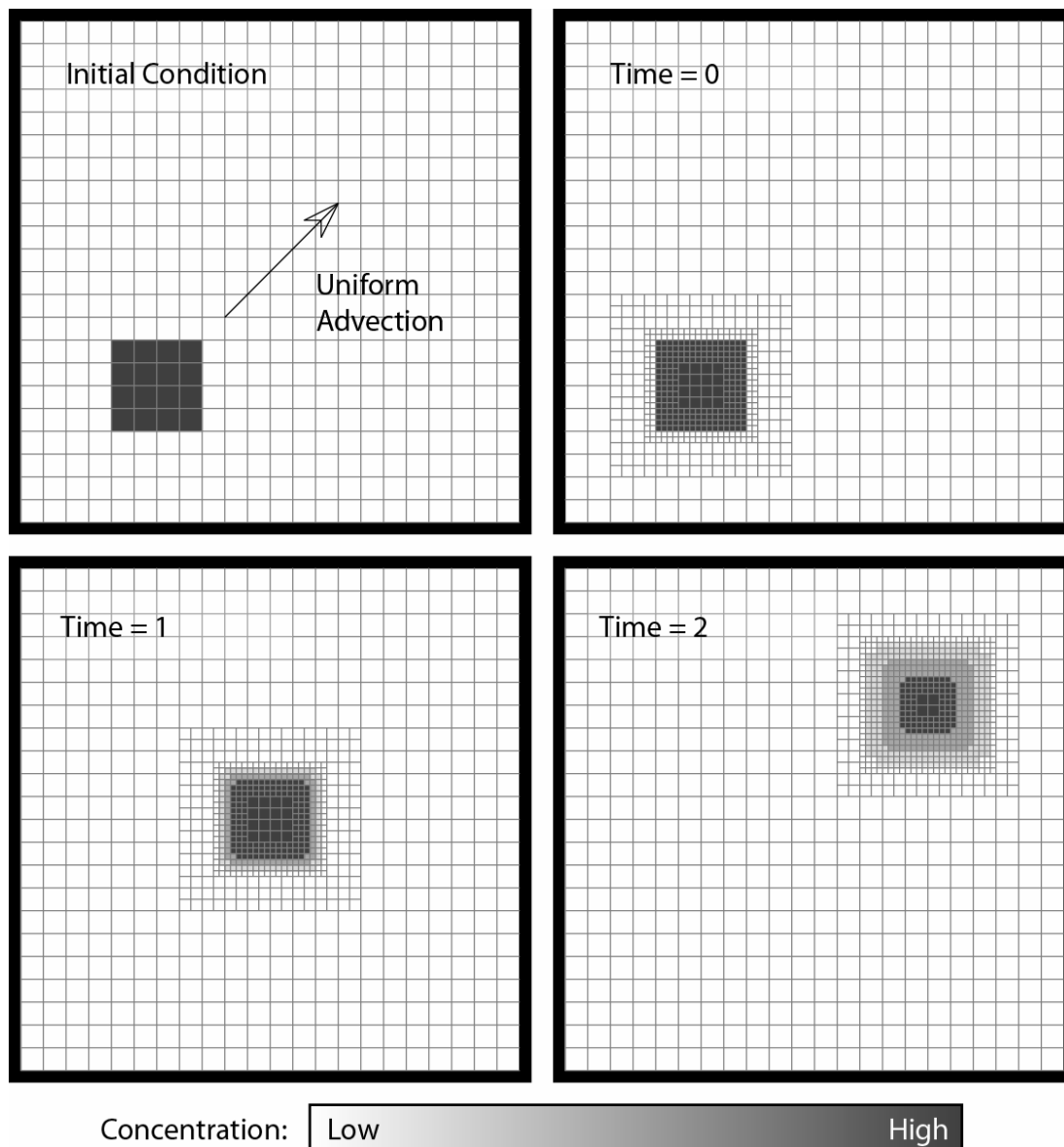
Figure 2.1: Advection in a Uniform Velocity Field, Showing Adaptive Mesh Refinement.

Expert outside help will be required in some areas. Contracts were initiated for a programmer, GIS assistance, and LBNL expertise. In December 2003 a contract programming expert was signed. A GIS contract was awarded in January 2004 to the Michael Thomas Group and work started in April 2004. A contract with LBNL is expected to be finalized for next Fiscal Year (2004-05).

Project meetings are held weekly to move the project from concept to design and address technical issues as they arise. Management meetings are held monthly to discuss and resolve administrative issues and review progress.

Some features planned for REALM have been tested using a new version of DSM2 as a test platform. This approach improves the functionality of our current Delta model and allows us to experiment and learn about proposed REALM features in a simpler environment. Features implemented in this manner in DSM2 include:

❑ Connection to a relational database for all non-time-varying data.

❑ A Graphical User Interface (GUI) to allow users to access and edit information in the database.

❑ New ways of implementing gates.

❑ Partial use of operating rules that are limited to hydrodynamic parameters such as stage and flow, and gate operations only.

2.4 Funding Scenarios

Three scenarios with different financial resources have been developed. All scenarios lead to a fully functional 1D-2D hydrodynamics and water quality model with GIS graphical support and particle tracking by the end of 2006. The model will include support for AMR, embedded boundaries and parallelization, and wetting and drying.

The scenarios differ in the timing and number of features offered. In the low and medium budget scenarios, it is possible to complete some advanced computational features such as 3D modeling and adjoint optimization capabilities, but not to package these features in a finished application within the 2006 planning horizon.

Table 2.1: Comparison of Deliverables near the End of 2006.

Features/Funding Levels	Low	Med	High
Calibrated model 1D-2D	Jul 2006	Mar 2006	Jan 2006
3D solver (no GUI)	Dec 2006	Aug 2006	May 2006
3D full application			Jul 2006
Optimization capability (adjoint)	Mar 2006	Dec 2005	Dec 2005
Multi-objective optimization with GUI	> 2 years	> 2 years	May 2006
Real-time data assimilation, no GUI (Kalman filter)	> 2 years	Jun 2006	Feb 2006
Real-time data assimilation application	> 2 years	> 2 years	Apr 2006
Automated calibration	> 2 years	> 2 years	Sep 2006
1D-2D technical docs	Minimal (usage only)	Minimal (usage only)	Full with tutorial (Jan 2006)
3D, particle, graphics documentation	> 2 years	> 2 years	Sep 2006

2.5 Feature Priority

❏ *Relevance*
Features should solve problems of high benefit to the Department, SWP, Delta operations, and the State in general. The problems should be of enough importance to make solving them compelling.

❏ *Not solvable by other means*
Features should solve problems that have not been solved yet, and the problems should be largely or entirely unsolvable with other means or tools. Or, other tools will only give approximate or qualitative solutions, when a REALM feature could provide a precise, quantitative solution which makes a substantial difference in benefit.

❏ *Ease of implementation*
Features easy to implement, even though marginally useful, might be preferred over difficult implementations.

It was important to identify real-world problems that a REALM feature could solve. The following questions were posed to engineers, environmental scientists, and managers who have a history of direct involvement in solving Delta issues:

> *"What problems or questions in the Delta would you like to resolve, that you cannot because of limitations in current tools? What problems would you solve if tool limitations were not an issue?"*

Interview responses are available at:
http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/news/realmstatus032004.pdf

2.6 Reference

Ateljevich, E. and R. Finch. (2003). "Chapter 2: REALM." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 24th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Bay-Delta Office. Sacramento, CA.

2.7 Website

Continuing updates concerning REALM can be found at:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/news/realm.cfm

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

25th Annual Progress Report
October 2004

Chapter 3:
DSM2 Geometry Investigations

Authors: Bob Suits and Jim Wilde

3 DSM2 Geometry Investigations

3.1 Introduction

Since the DSM2 Project Work Team (PWT) recalibrated DSM2 to flow, stage, and EC in 1999, new flow data have been collected (Nader-Tehrani, 2001). This chapter summarizes investigations to validate DSM2 with the new flow data and explore geometry changes to DSM2 to better model Delta hydrodynamics.

3.2 Franks Tract Representation

From April 2002 through September 2002, the U.S. Geological Survey (USGS) collected 10-minute flow data at six locations surrounding Franks Tract (Figure 3.1) to better understand tidal flow across Franks Tract. In addition, a superficial survey of channel openings to Franks Tract was conducted by USGS. Based upon this data, the Delta Modeling Section first validated DSM2 with the new flow data, then experimented with various representations of Franks Tract using the new flow information in order to improve upon DSM2.
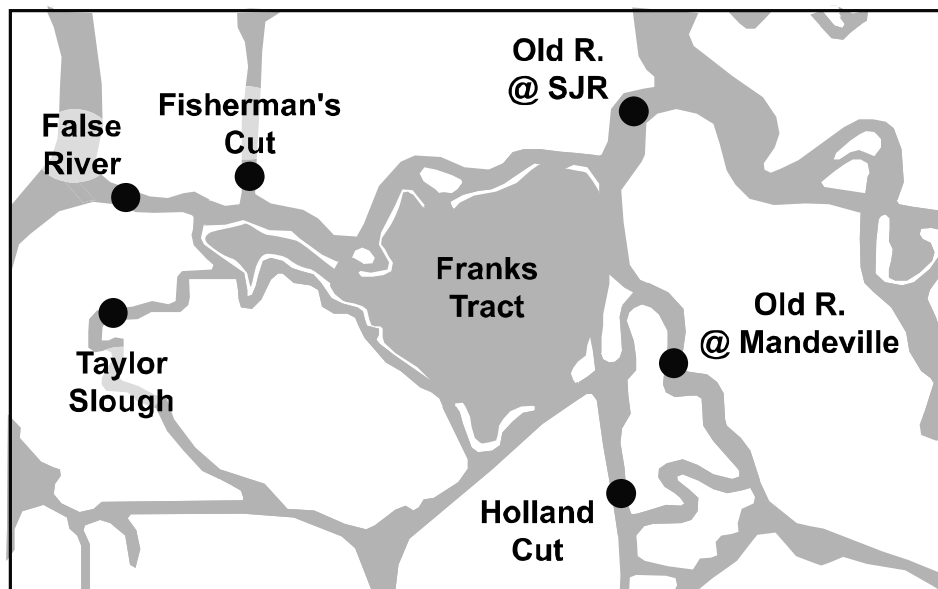
Figure 3.1: Locations of Flow Data Collected by USGS, April 2002 – September 2002.

3.3 DSM2 Validation with New 2002 USGS Flow Data

DSM2 flow results from the historical April 2002 through September 2002 simulation were compared to the field data collected by USGS. Figure 3.2 shows the 15-minute DSM2-simulated flows and the 10-minute USGS measured flows over the period of May 1, 2002 through May 5, 2002 at the six locations in Figure 3.1. This period, although short in comparison to the five months for the study, is typical of the results at these locations. Figure 3.3 shows the 24.75-hour twice-averaged (filtered) flow data at the same locations over the duration of the data sampling period. Included in Figure 3.3 for later comparison are the filtered flow values for Alternative 3g, which is described and discussed later. For the current configuration of Franks Tract and the surrounding channels, DSM2 tends to underestimate the peak tidal flows at Holland Cut, Old River at Mandeville Island, and False River. In comparison, the DSM2-simulated tidal flows in Taylor Slough and Fisherman's Cut exceed those measured, although the magnitude of the flows here is significantly less than at the other locations studied. At the Old River site near the San Joaquin River, DSM2 tends to match the peak ebb flow, but significantly overestimates the peak flood flow. As a result, the average flow calculated by DSM2 here was consistently approximately 3,000 cfs higher than the measured flow in the upstream direction (Figure 3.3).
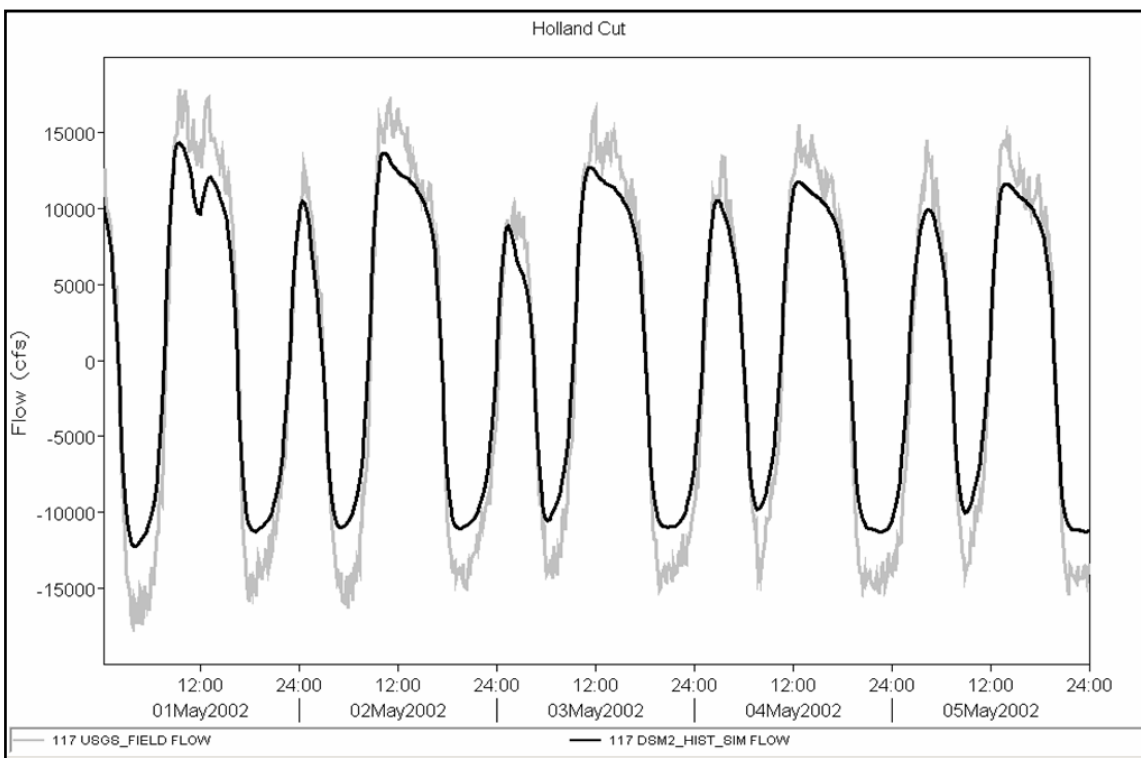
Figure 3.2a: DSM2 Generated Flow (Current Geometry) and USGS Field Data, Holland Cut, May 1 – May 5, 2002.
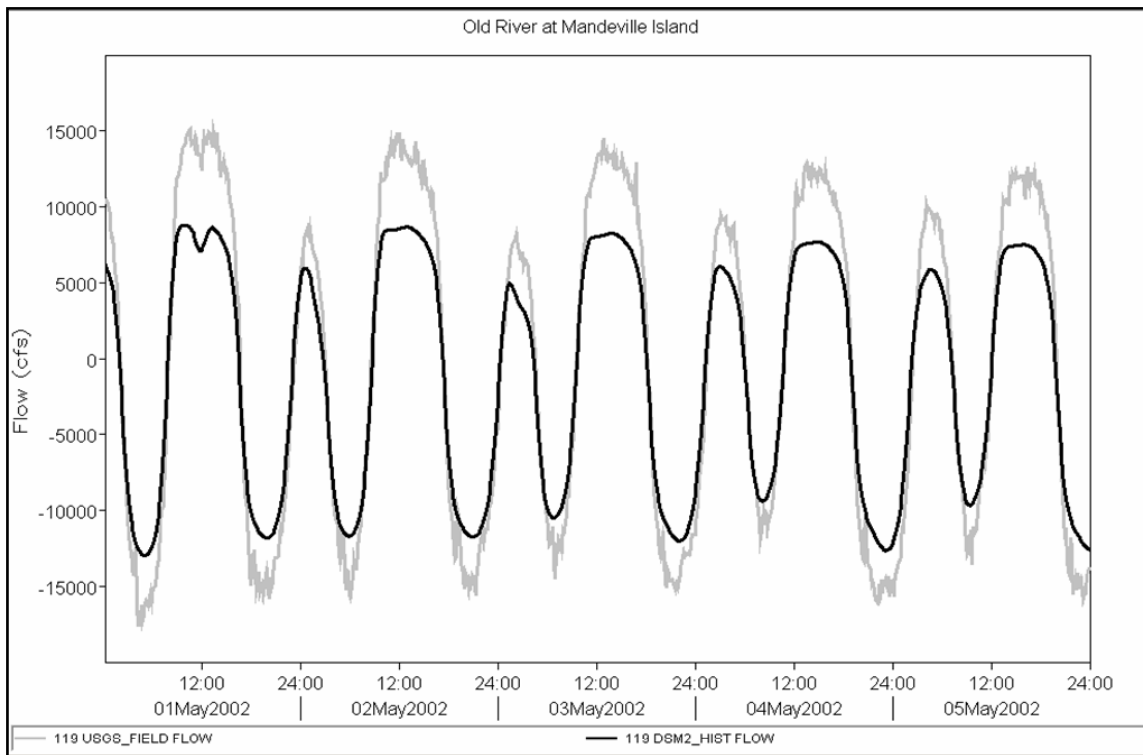
Figure 3.2b: DSM2 Generated Flow (Current Geometry) and USGS Field Data, Old River at Mandeville Island, May 1 – May 5, 2002.
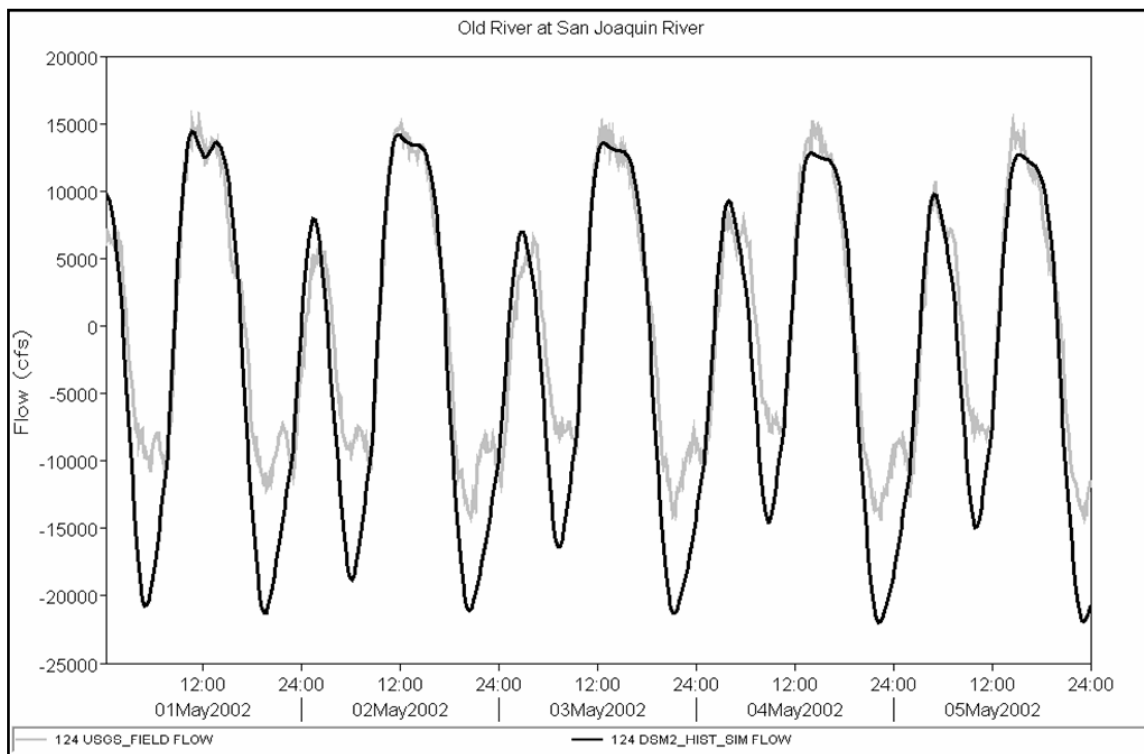
Figure 3.2c: DSM2 Generated Flow (Current Geometry) and USGS Field Data, Old River at San Joaquin River, May 1 – May 5, 2002.
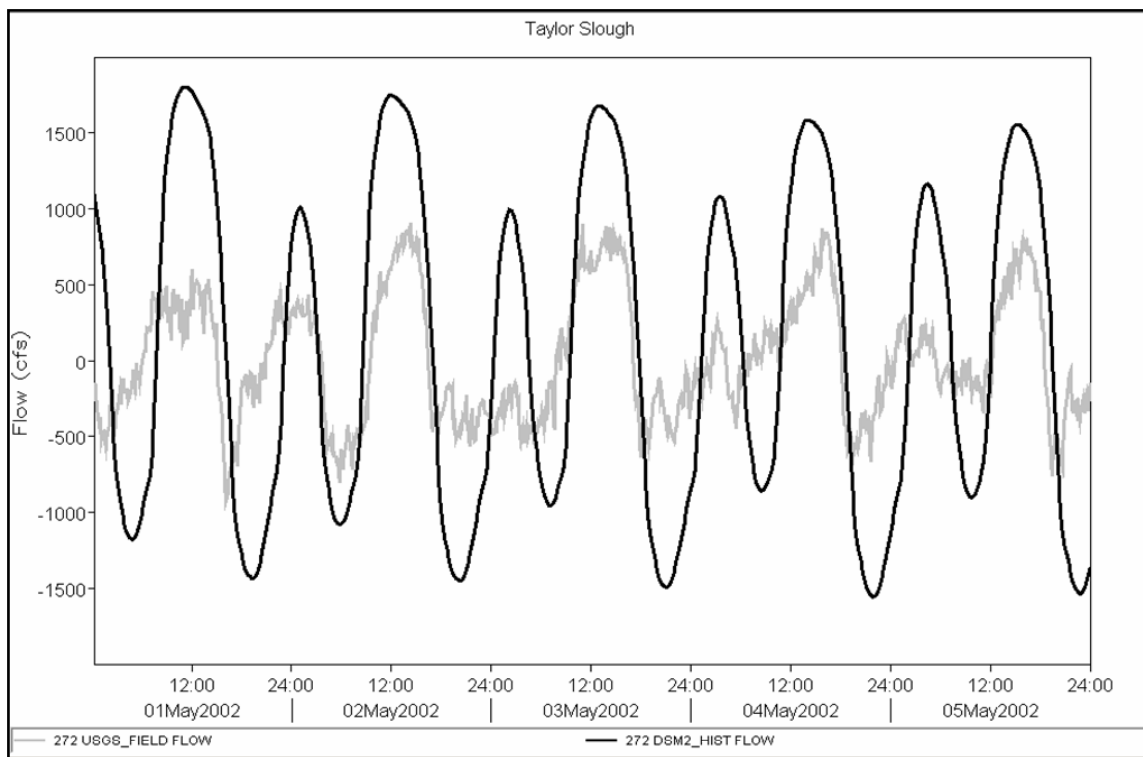
Figure 3.2d: DSM2 Generated Flow (Current Geometry) and USGS Field Data, Taylor Slough, May 1 – May 5, 2002.
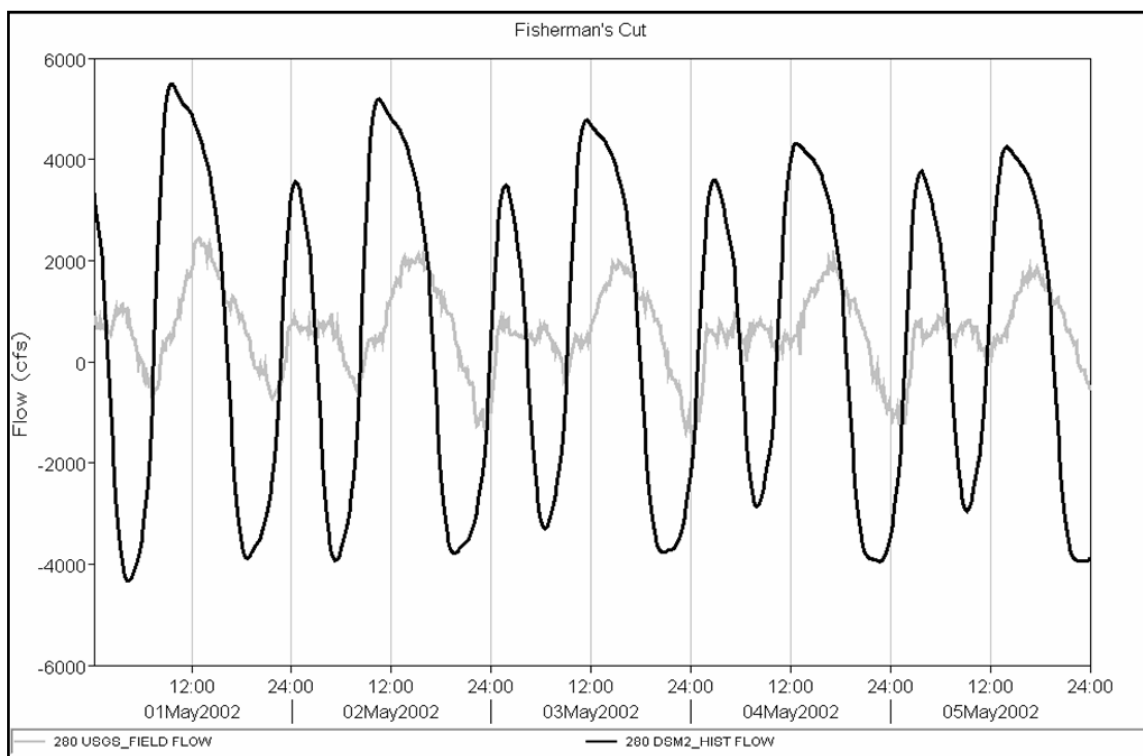
Figure 3.2e: DSM2 Generated Flow (Current Geometry) and USGS Field Data, Fisherman's Cut, May 1 – May 5, 2002.
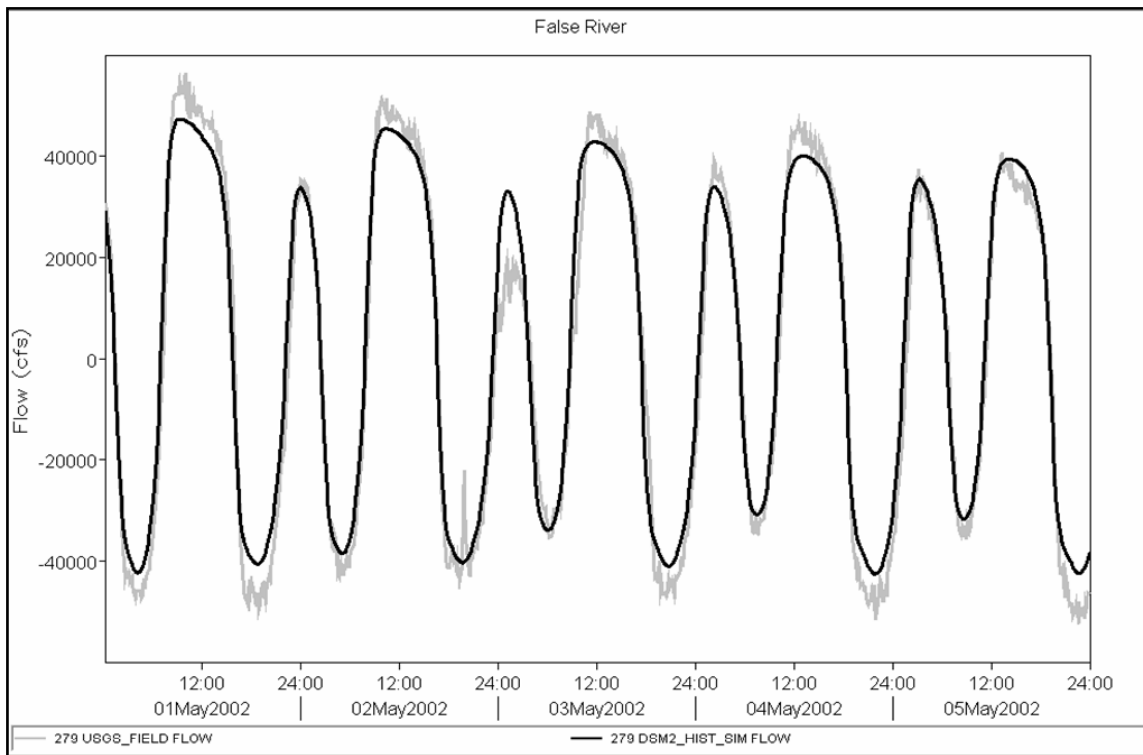
Figure 3.2f: DSM2 Generated Flow (Current Geometry) and USGS Field Data, False River, May 1 – May 5, 2002.

In general, for a given location, differences in between DSM2 and field-measured average flow tended to be about the same magnitude for the duration of the study period. DSM2 consistently overestimated average flow in the downstream direction at Holland Cut (about 1,000 cfs) and at False River (about 2,000 cfs). DSM2 overestimated average flow in the upstream direction at Old River at Mandeville Island (about 1,000 cfs), while average flow values at Taylor Slough and Fisherman's Cut were approximately the same.

The error in DSM2 flows in Old River near the San Joaquin River is consistent with the hypothesis that DSM2 underestimates the tidal flood flow across Franks Tract, though to what extent is unknown. It was believed that modifying DSM2 geometry to improve the flow simulated here would improve the simulation of flow elsewhere. Therefore, a series of changes to the representation of Franks Tract in DSM2 were tested by comparing simulated flows in Old River near the San Joaquin River to the measured values.
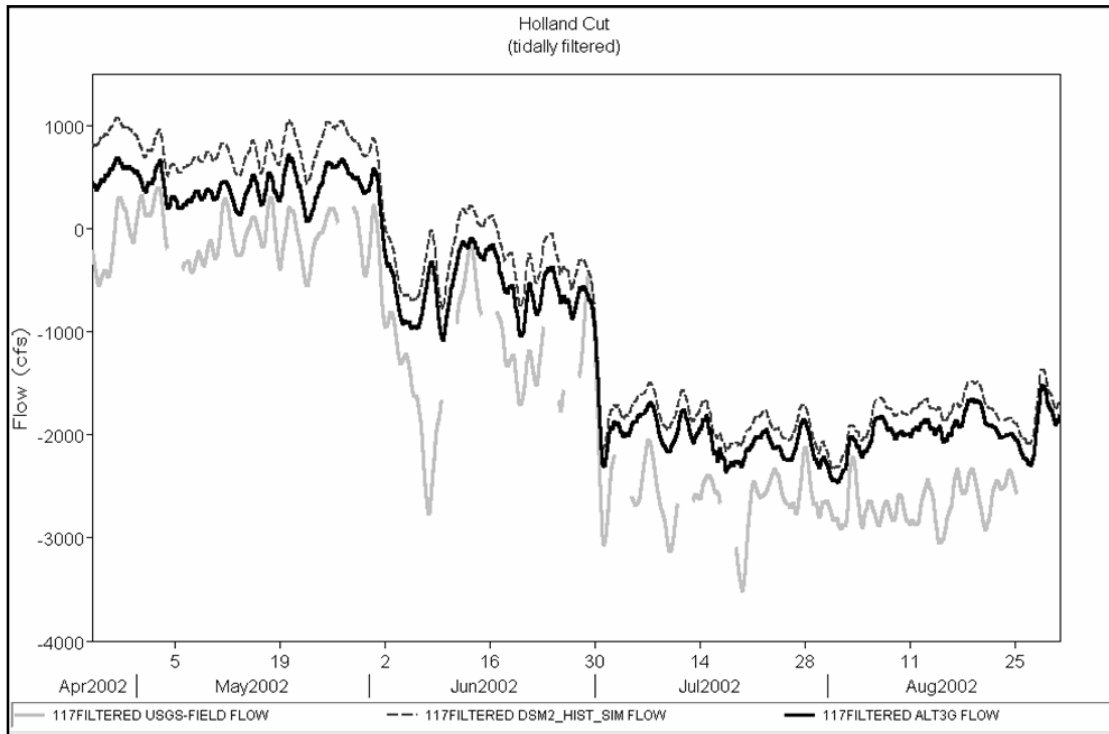
Figure 3.3a: Filtered Daily Average Flow: DSM2 Generated Flow for Existing, Alt 3g, and USGS Field Data, Holland Cut, 2002.
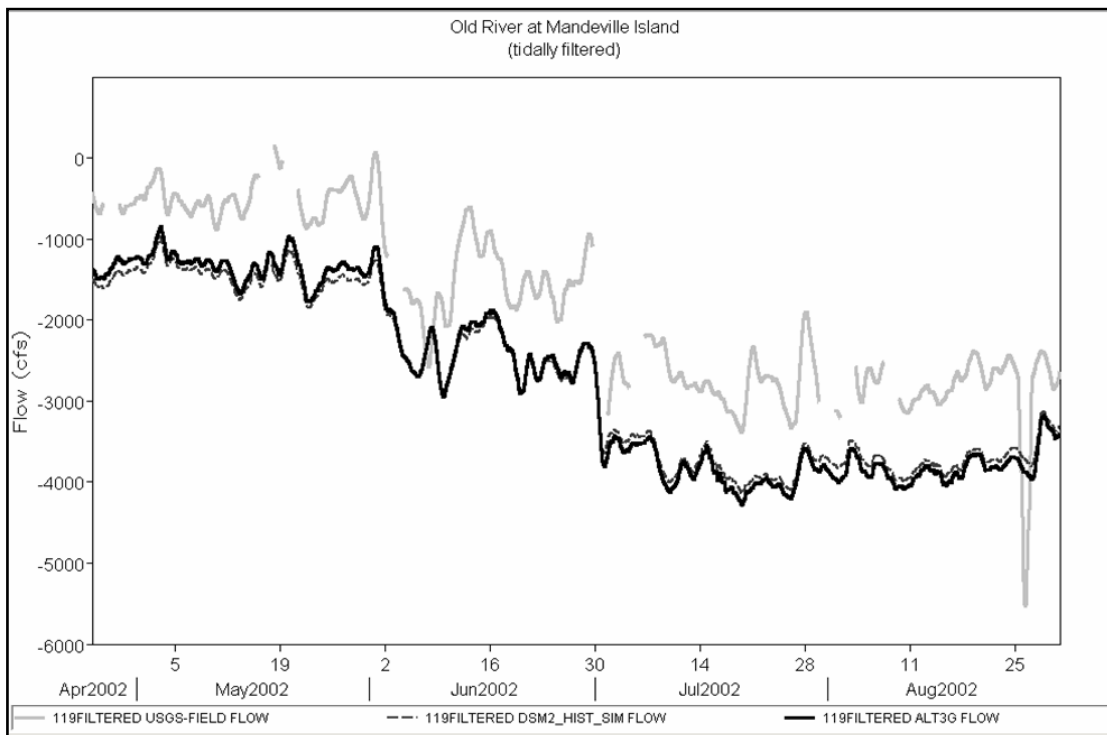
Figure 3.3b: Filtered Daily Average flow: DSM2 Generated Flow for Existing Alt 3g, and USGS Field Data, Old River at Mandeville Island, 2002.

Figure 3.3c: Filtered Daily Average Flow: DSM2 Generated Flow for Existing, Alt 3g, and USGS Field Data, Old River at San Joaquin River, 2002.
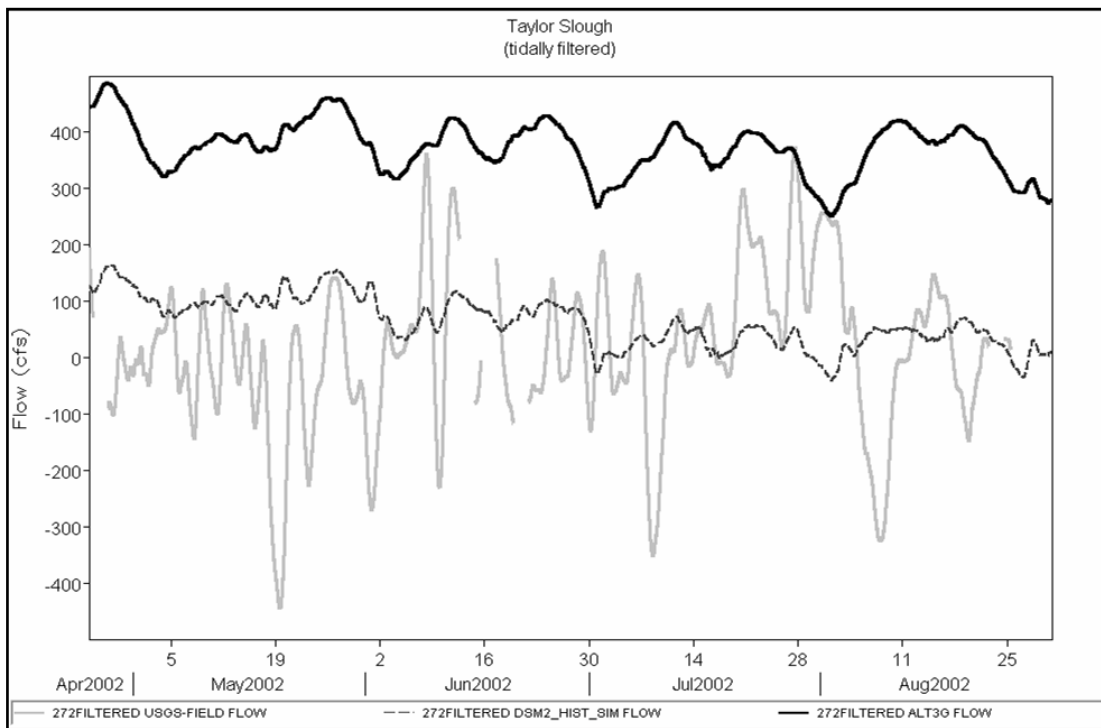
Figure 3.3d: Filtered Daily Average Flow: DSM2 Generated Flow for Existing, Alt 3g, and USGS Field Data, Taylor Slough, 2002.
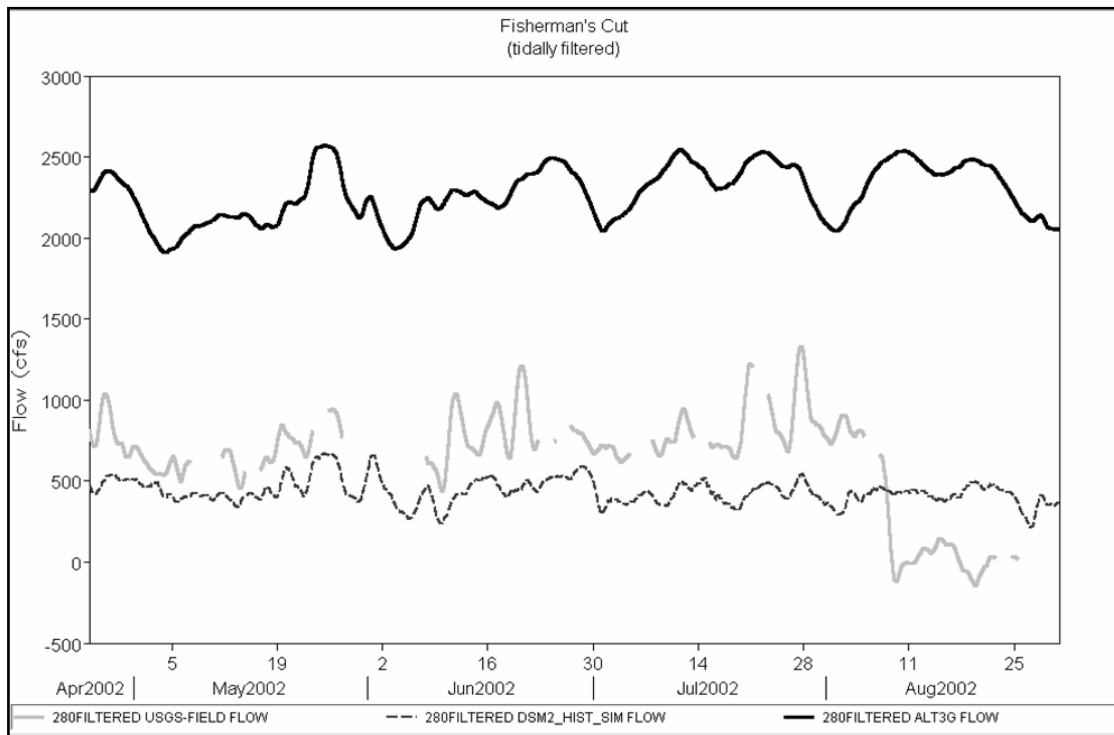
Figure 3.3e: Filtered Daily Average Flow: DSM2 Generated Flow for Existing, Alt 3g, and USGS Field Data, Fisherman's Cut, 2002.
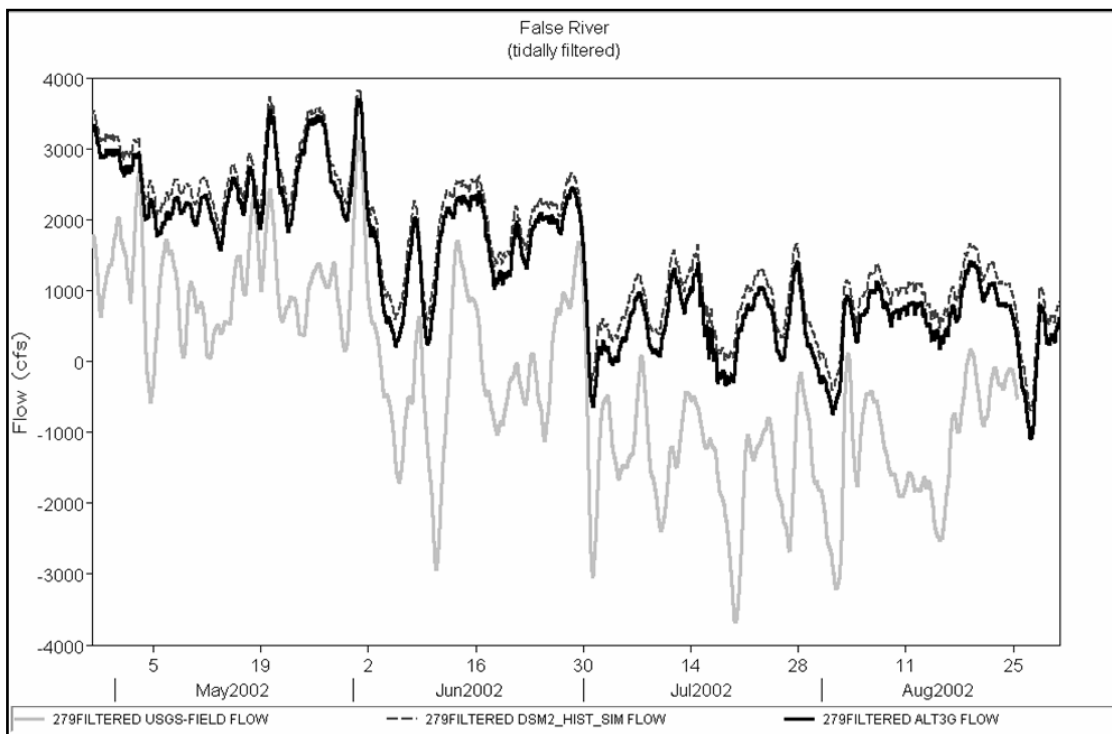
Figure 3.3f: Filtered Daily Average Flow: DSM2 Generated Flow for Existing, Alt 3g, and USGS Field Data, False River, 2002.

3.4 Experimenting with Changes to Franks Tract Representation

The current configuration of Franks Tract in DSM2 consists of an open area with surface area of 141,786,000 sq. ft. (3,255 acres) hydraulically connected to Delta channels at six locations (Figure 3.4 and Table 1). Flow into and out of the open area is determined by an orifice flow equation: $Q = CA\sqrt{2g\Delta h}$ where Q is flow, (CA) is the "flow coefficient", A is the flow cross-sectional area, and Δh is the difference in stage. Flow coefficients can vary by flow direction (inflow and outflow). The source of the current flow coefficients for Franks Tract in DSM2 is not well documented, but the values most likely came from examining topographic maps and navigation charts and do not change for direction of flow (Table 3.1).
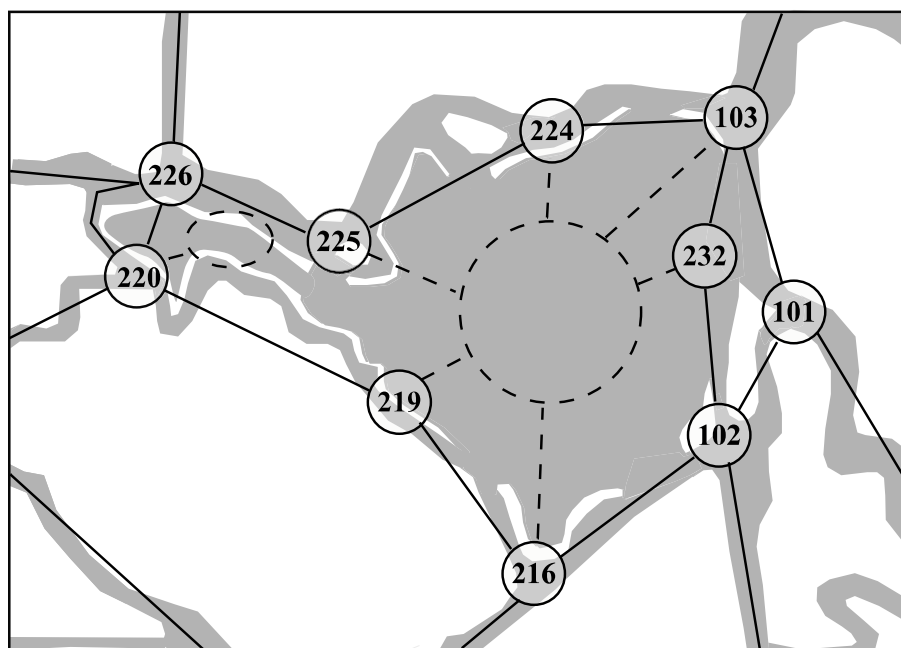
Figure 3.4 Current DSM2 Representation of Franks Tract.

Modifications to the representation of Franks Tract were explored with the goal of first using more realistic opening dimensions into Franks Tract (Alternative 1a), then trying to better simulate flow across the open area as indicated by better simulation of flow in Old River near the San Joaquin River (Alternatives 1d, 2d, and 3g). Table 3.1 lists how the different alternatives varied in simulating connections between Franks Tract and the surrounding channels.

The flow coefficients (Table 3.1) are the only difference between the existing DSM2 description of Franks Tract and Alternative 1a. Alternative 1d attempts to account for the effects of the remnants of an island levy, now a submerged berm, that runs along the east side of Franks Tract (Figure 3.5) by restricting flow between the open area and nodes 232 and 102 on the east side. An additional node, 234, was added and then connected to nodes 232 and 102 by shallow, wide channels. Egeria densa in the southern part of Franks Tract was represented by replacing 1/3 of the open reservoir with wide channels with a higher roughness coefficient (see Figure 3.6 for Alternative 2d). Finally, Franks Tract was simulated by replacing the entire open area with four wide channels, with the southern channels again with roughness coefficients indicative of Egeria (Figure 3.7 for Alternative 3g). Table 3.1 summarizes the hydraulic connections of Frank Tract

to surrounding channels for these alternatives. For Alternative 3g , a minor modification was made in Holland Cut's channel geometry near Franks Tract after the configuration in Franks Tract was set.

Table 3.1: Characteristics of Connections of Franks Tract to Surrounding Channels under Various Alternative DSM2 Descriptions.

Node	(Coefficient*Area) for Nodes Connected to Open Area in Franks Tract (ft^2)									
	Existing		Alt 1a		Alt 1d		Alt 2d		Alt 3g	
	in	out	in	out	in	out	in	out	in	out
103	3000	3000	1300	1300	1300	1300	1300	1300	channel	
232	3000	3000	3000	3000			3000	3000		
234					3000	3000				
102									channel	
216	2000	2000	3000	3000	3000	3000	channel			
219	2000	2000	9000	9000	9000	9000	channel		channel	
225	2000	2000	11000	11000	11000	11000	11000	11000	channel	
224	3000	3000	13500	13500	13500	13500	13500	13500		

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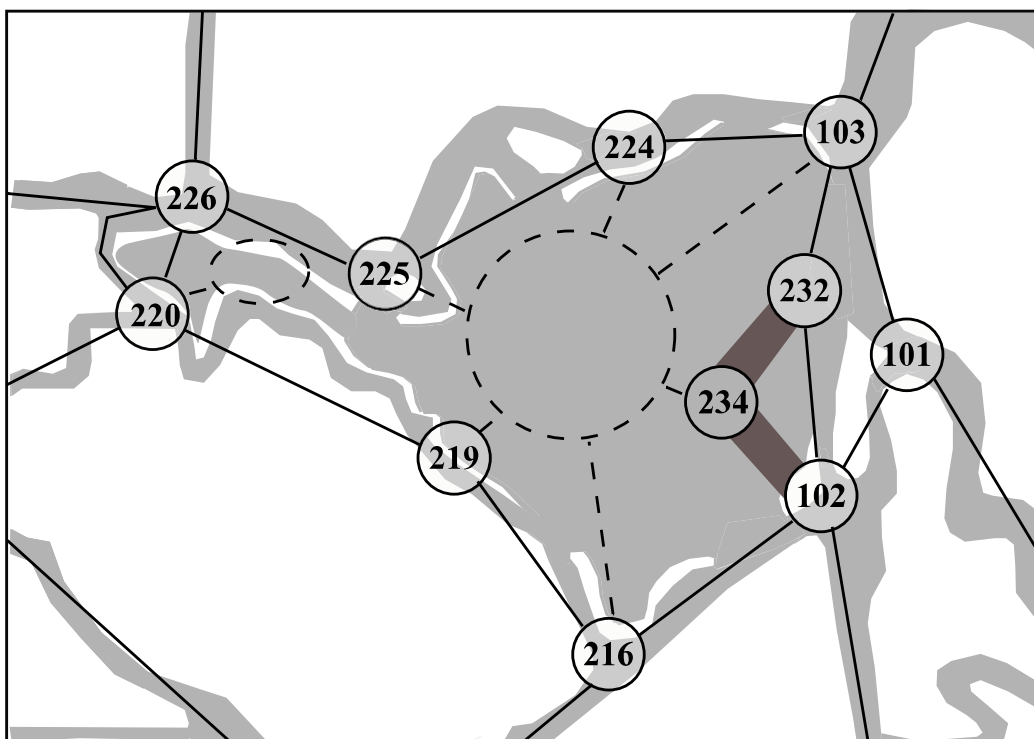
Figure 3.5: DSM2 Representation of Franks Tract for Alternative 1d (simulation of submerged berm on east end).
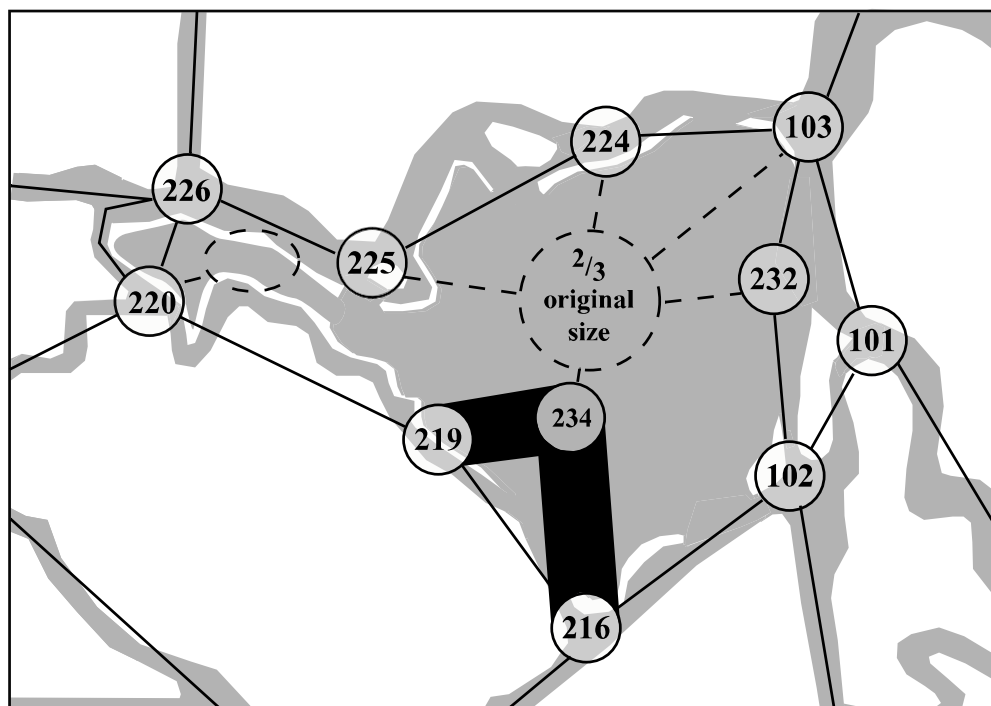
Figure 3.6: DSM2 Representation of Franks Tract for Alternative 2d (simulation of southern portion by wide channels).
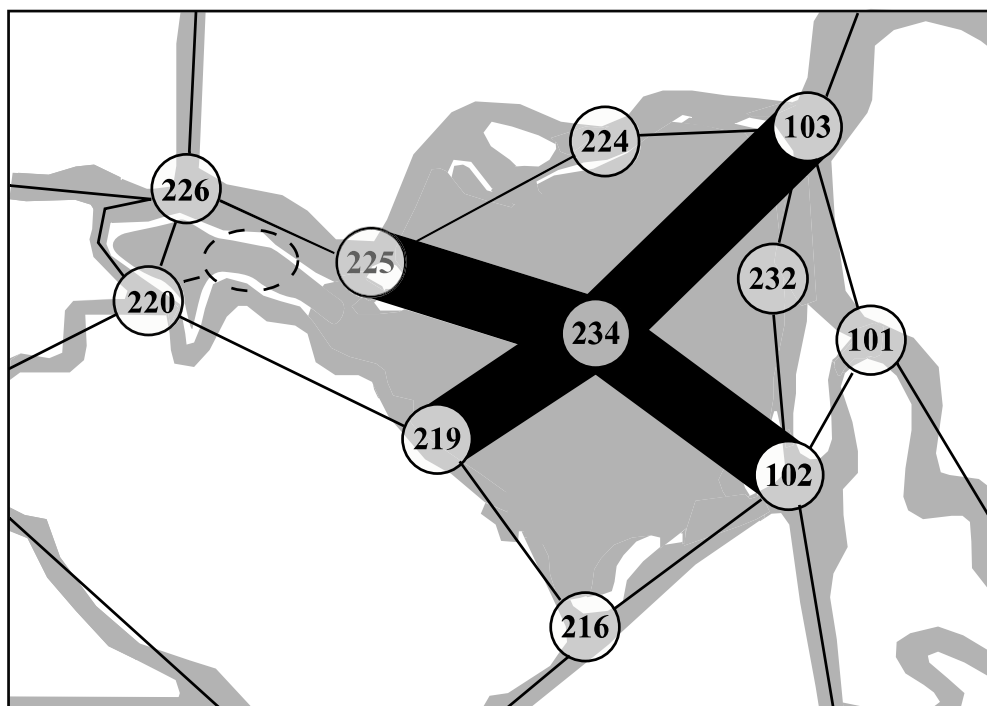
**Figure 3.7: DSM2 Representation of Franks Tract for Alternative 3g
(simulation of entire flooded area by wide channels).**

DSM2 simulations of these alternatives at Old River near the San Joaquin River for the May 1-5, 2002 period are shown in Figure 3.8. As mentioned before, the measured instantaneous flow and averaged measured flow in Old River near the San Joaquin River were used as an indication of the effectiveness of a representation of Franks Tract in DSM2.

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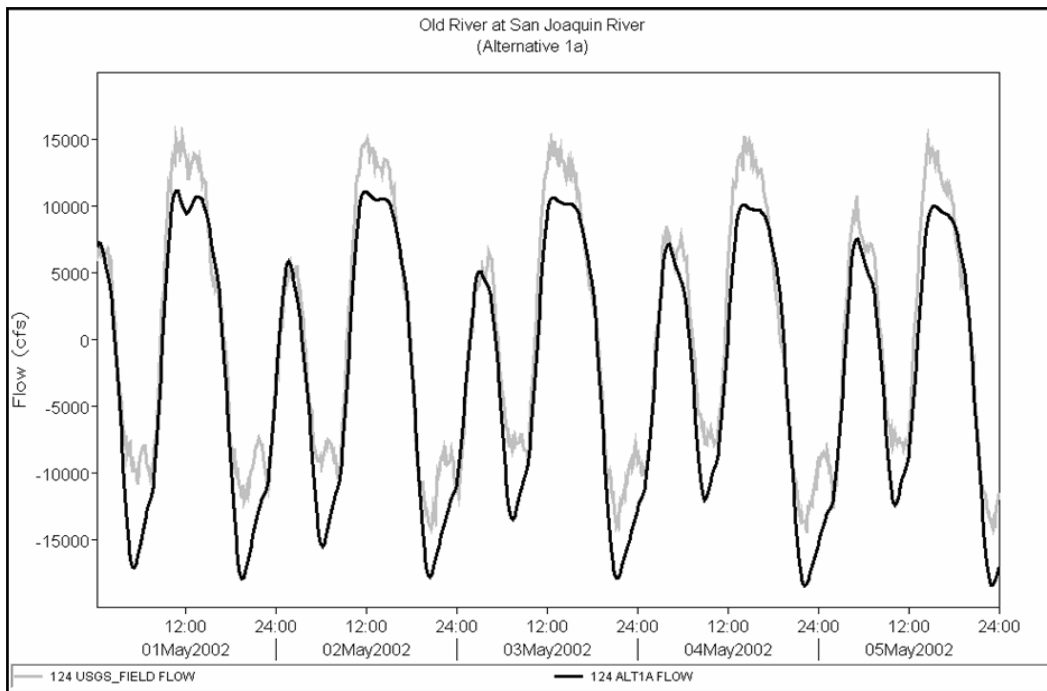
Figure 3.8a: DSM2 Alt 1a Generated Flow and USGS Field Data, Old River at San Joaquin River, May 1 – May 5, 2002.
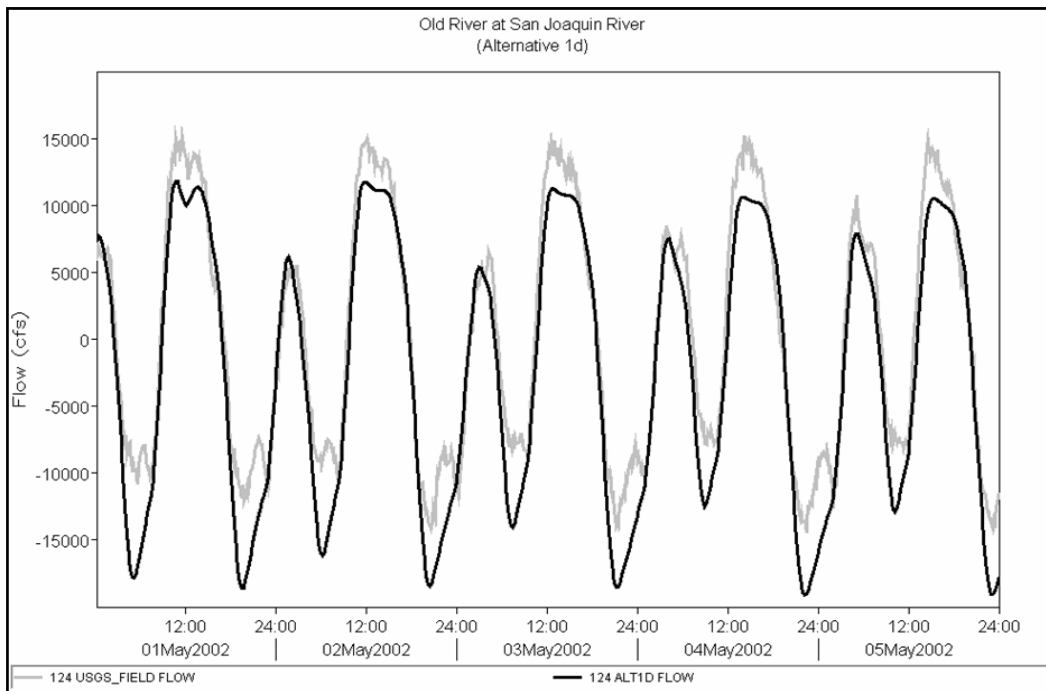
Figure 3.8b: DSM2 Alt 1d Generated Flow and USGS Field Data, Old River at San Joaquin River, May 1 – May 5, 2002.
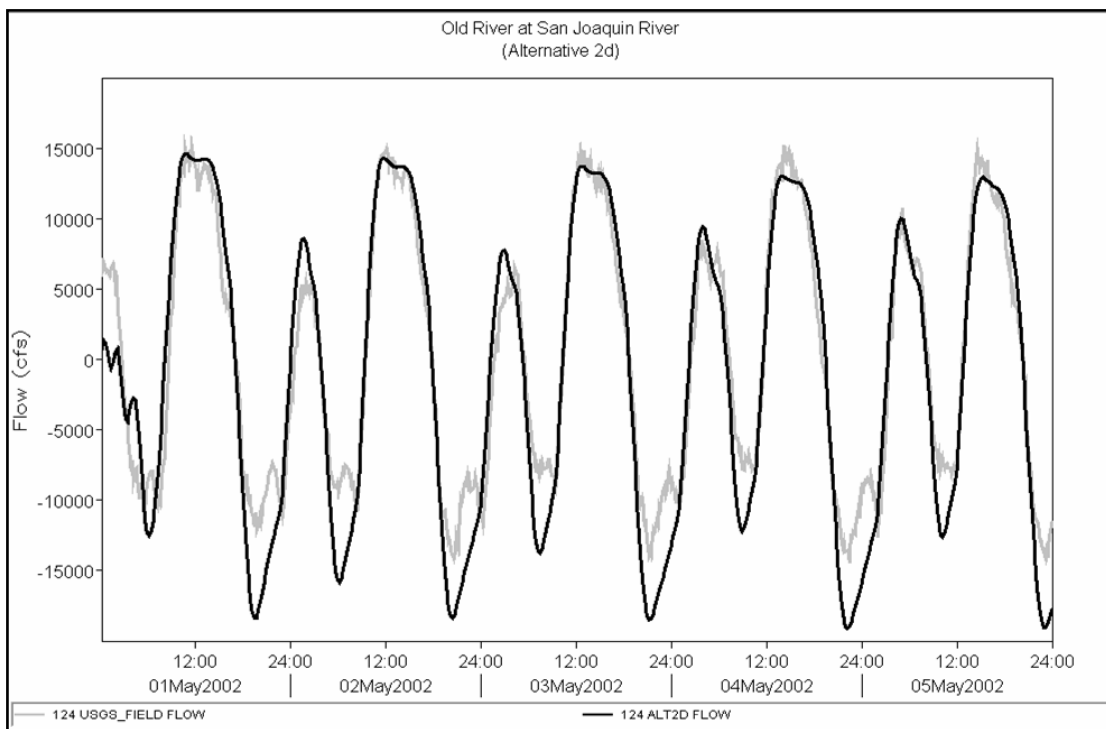
Figure 3.8c: DSM2 Alt 2d Generated Flow and USGS Field Data, Old River at San Joaquin River, May 1 – May 5, 2002.
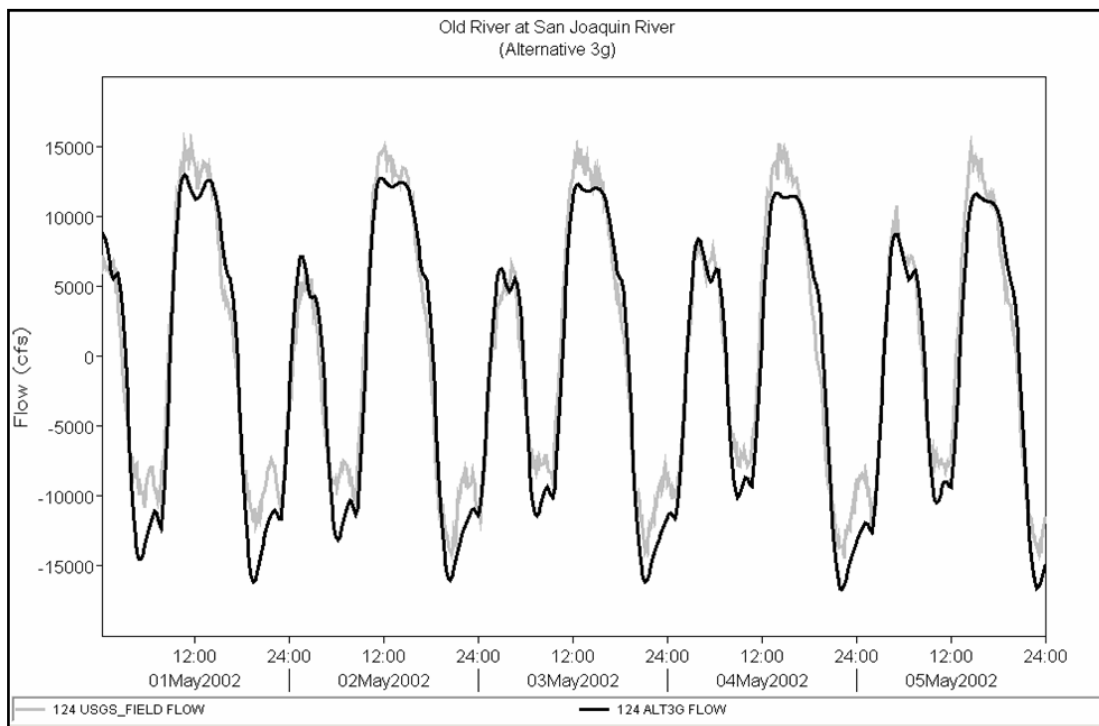
Figure 3.8d: DSM2 Alt 3g Generated Flow and USGS Field Data, Old River at San Joaquin River, May 1 – May 5, 2002.

3.5 Experimenting with Changes to Surrounding Channels

Alternative 3g included minor changes to several irregular cross sections in Holland Cut. Early on in the study, it was clear that improving the simulation of flow in Holland Cut, Fisherman's Cut, and Taylor Slough would not significantly affect the flow across Franks Tract, which is the primary concern. After the configuration of Franks Tract as a series of shallow, wide channels was shown to be best at recreating flows in lower Old River, Alternative 3g was formulated combining the characterization of Franks Tract as channels and modifying the geometry in Holland Cut. Therefore, only Alternative 3g is shown with this feature in an alternative.

3.6 Average Flows under Alternative 3g

The filtered DSM2-simulated flows at the six study locations are presented in Figure 3.3 along with the filtered field data and the DSM2-simulated flows from the current geometry description. As Figure 3.8d shows, DSM2-simulated average flow under Alternative 3g was much closer to field-measured flow at the Old River at San Joaquin River site; however, modeled average flow remains about 1,000 cfs too high in the upstream direction. At Holland Cut and False River, minor improvements in flow resulted and Old River at Mandeville Island experienced little change in flow. At Taylor Slough and Fisherman's Cut, average flow under Alternative 3g significantly increased in the direction towards Franks Tract, presumably as a result of inducing more tidal flow upstream into Franks Tract. As a result, the error in average flows in these two channels significantly increased.

3.7 Delta EC under Alternative 3g

Historic Delta EC conditions were simulated under Alternative 3g. These results, not presented here, varied only slightly from the EC modeled by the current DSM2 geometry, including Franks Tract. The Delta dispersion coefficients downstream of Franks Tract were viewed as limiting any improvement in EC that may occur. Thus, substantial improvements in modeled EC, even with improved flows, may rely on a recalibration of the dispersion coefficients in QUAL west of Franks Tract.

3.8 Discussion

To date, Alternative 3g is an indication of the possible improvement in DSM2-simulated flow at the six locations studied by USGS that can be accomplished without an extensive recalibration of DSM2 beyond the local area of Franks Tract.

To improve DSM2's performance in flow beyond what is presented here in Alternative 3g will require a recalibration of the Manning's n values in HYDRO. To take advantage of improved simulation of flows to improve the accuracy of simulated EC, a subsequent recalibration of the dispersion factors in QUAL would be needed.

3.9 Reference

Nader-Tehrani, P. (2001). "Chapter 2: DSM2 Calibration and Validation." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 22nd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Office of State Water Project Planning. Sacramento, CA.

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

25th Annual Progress Report
October 2004

Chapter 4:
Modeling Dissolved Oxygen and Temperature in DSM2 Planning Studies

Author: Hari Rajbhandari

4 Modeling Dissolved Oxygen and Temperature in DSM2 Plannning Studies

4.1 Introduction

DSM2 was used to simulate dissolved oxygen (DO) in the Delta as part of the technical studies for the In-Delta Storage Project Feasibility Study (DWR, 2004). The goal of the In-Delta Storage Project is to provide water supply through using Bacon and Webb Tract Islands as intermittent reservoirs in order to supplement the Delta water supply and provide operational flexibility. The DSM2 study assessed potential DO and temperature impacts of releases from the islands over the standard 16-year sequence of hydrology from CALSIM II output used in Delta planning studies. DSM2 had been used in the past to model how low DO levels in the Deep Water Ship Channel (DWSC) near Stockton respond to increased San Joaquin River flow (Rajbhandari, 2004); however, because of data availability, this study was based on simulating a few recent years. Thus, for the In-Delta Storage Project, boundary conditions needed to be established in order to simulate DO and temperature once hydrodynamics had been modeled over the 1975 – 1991 planning period (Figure 4.1). This chapter describes the procedure used to develop the boundary conditions to enable DSM2 simulation of DO and temperature under a typical planning scenario.
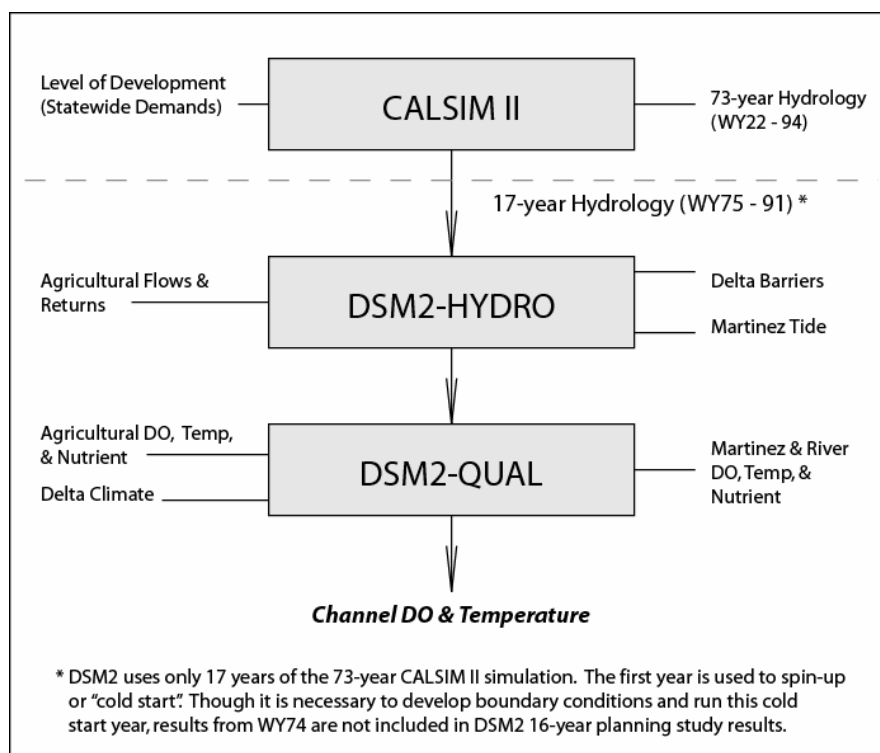
Figure 4-1: Planning Study Methodology.

4.2 General Methodology

4.2.1 DO Modeling Data Requirements

The input parameters needed to model DO include water temperature, biochemical oxygen demand (BOD), chlorophyll, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus (ortho-phosphate). A conceptual model showing the interaction among water quality variables in DSM2 is shown in Figure 4.2, with temperature affecting the rates of mass transfer. Recent work on calibration and validation of DSM2 for DO is documented in Rajbhandari et al. (2002). The conceptual and functional descriptions of constituent reactions represented in DSM2 are generally based on QUAL2E (Brown and Barnwell, 1987) and Bowie et al. (1985).
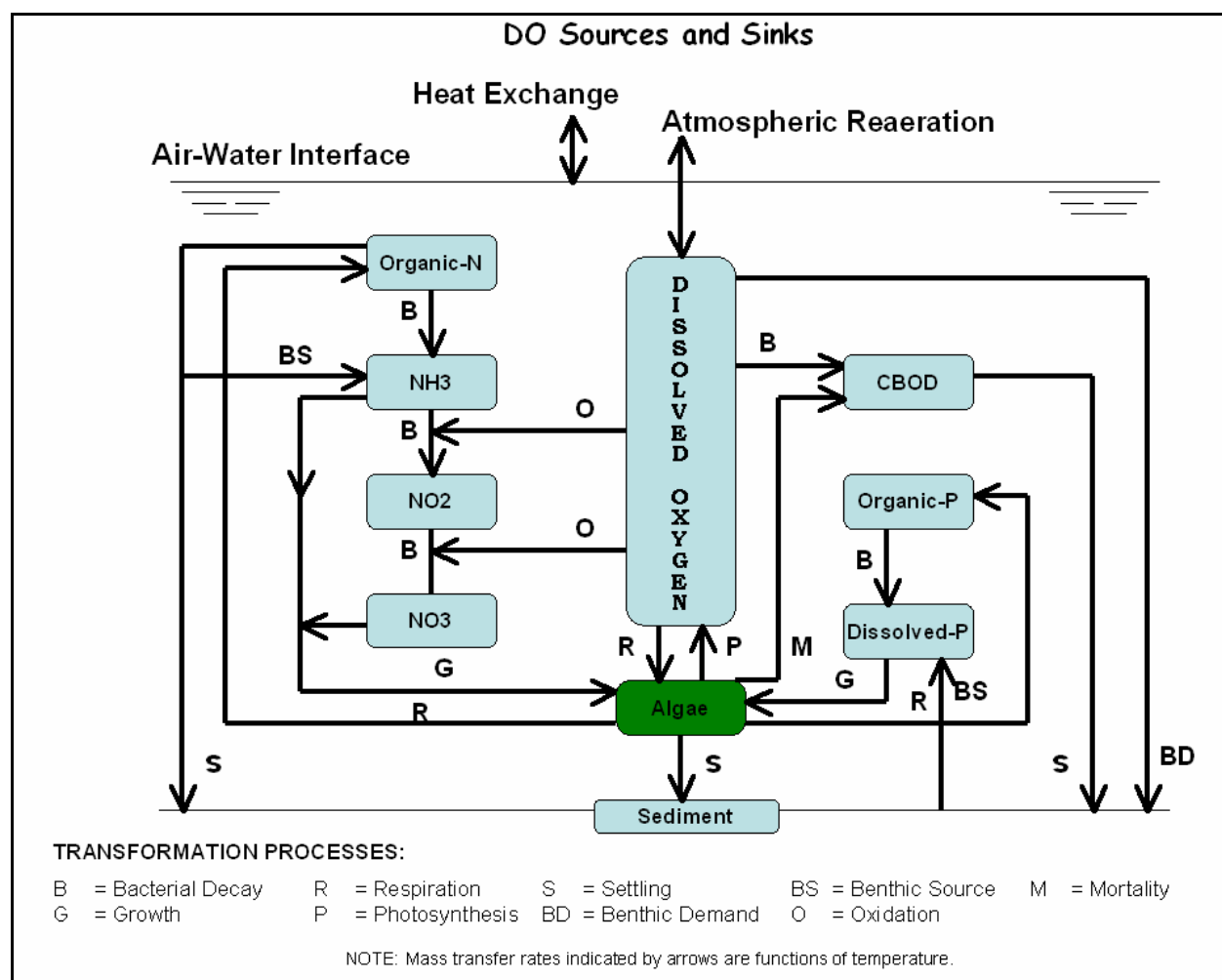
Figure 4.2: DO and Interaction Among Water Quality Parameters.

For DSM2 Delta water quality simulations, water quality data typically need to be provided for the major sources of inflow (the Sacramento River, San Joaquin River, Yolo Bypass, and Cosumnes/Mokelumne rivers), the downstream boundary at Martinez, and the agricultural return

flows within the Delta. Significant point sources may also be included, such as was the City of Stockton's Regional Wastewater Control Facility (RWCF). When simulating electrical conductivity (EC) in CASIM II–based planning studies, established flow-EC relationships at the Delta boundaries can be readily used to generate boundary EC, but no such relationships exist for the water quality parameters used in simulating DO. Thus, methods were developed to use available historical data to generate the data needed for modeling DO with DSM2 under hypothetical Delta hydrologies. For the purposes of this paper, this data is categorized according to water temperature and DO, nutrients, and climate. RWCF effluent water quality is considered separately.

4.2.2 Water Temperature and DO

Nearly continuous hourly water temperature and DO were available from 1997 through 2000 at Mossdale and Martinez and from 1999 through 2001 at Freeport. Although some water temperature and DO data from 1983 to present exist, no relationships with flow were observed so use of historic data was limited to more recent years. Daily average values were calculated from this data and used as boundary input: Mossdale data was used for Vernalis input and Freeport data was used for input at Sacramento, the Yolo Bypass, and Cosumnes/Mokelumne rivers. Daily average values from recent years were then assigned to individual years in planning studies by first assigning historical year 2000, a leap year, to leap years in the planning studies (1976, 1980, 1984, 1988), then assigning other historical years to years in planning studies in a repetitive sequencing (Table 4.1).

**Table 4.1: Assignment of Historical Data to Planning Year for
Water Temperature and DO.**

Planning Year	Historical Year	Historical Year
	San Joaquin River Boundary Martinez Boundary	Sacramento River Boundary
1974	1998	1999
1975	1999	1999
1976	**2000**	**2000**
1977	1997	2001
1978	1998	1999
1979	1999	1999
1980	**2000**	**2000**
1981	1997	2001
1982	1998	1999
1983	1999	1999
1984	**2000**	**2000**
1985	1997	2001
1986	1998	1999
1987	1999	1999
1988	**2000**	**2000**
1989	1997	2001
1990	1998	1999
1991	1999	1999

Leap years highlighted in bold.

Water temperature and DO in agriculture drainage were assumed to be a constant 22°C and 5.1 mg/L respectively, based on estimates from Municipal Water Quality Investigation Data Request (1995).

4.2.3 Nutrients

Estimates of nutrient data for the model boundary at Vernalis were based on various sources. Jones and Stokes (1998) computed the concentrations of ammonia and BOD data at Mossdale as the flow-weighted monthly average values. These values were reported for each month during 1987-1995. As shown in Figure 4.3, monthly average chlorophyll from 1983 – 2001 at Vernalis was taken from Nieuwenhuyse (2002). Averages of these monthly values were used for each year in the planning study (Table 4.2). Nitrite nitrogen, nitrate nitrogen, organic nitrogen, phosphate, and organic phosphorus at Vernalis were estimated based on averaging the San Joaquin River Total Maximum Daily Load study measurements sampled at weekly intervals in 1999 (Table 4.3).
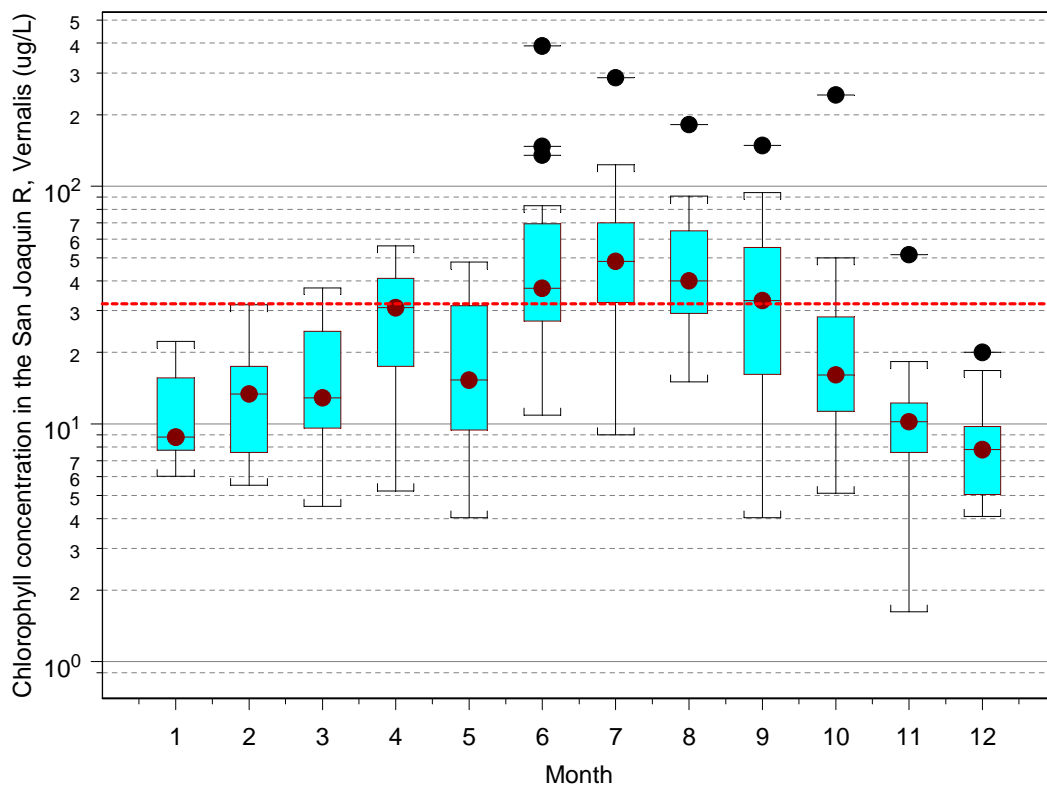
Figure 4.3: Summary Statistics for Monthly Average Chlorophyll Concentration in the San Joaquin River at Vernalis, 1983-2001. (Nieuwenhuyse, E.E.V., 2002)

Table 4.2: Monthly-Varying Nutrient Data at Vernalis.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Ammonia-N (mg/L)	0.39	0.31	0.09	0.03	0.02	0.01	0.02	0.03	0.02	0.02	0.05	0.07
BOD (mg/L)	2.1	2.2	2.8	3.4	4.0	6.0	6.2	5.4	4.9	4.0	2.1	1.7
Chlorophyll (µg/L)	9	15	13	31	15	35	50	40	32	17	10	8

Table 4.3 presents nutrient data at Freeport on the Sacramento River that were approximated from a U.S. Geological Survey report (USGS, 1997) and data at Martinez that was obtained from DWR (1997). Chlorophyll data for the Sacramento River and Martinez were approximated based on data reported by DWR (1999). Estimates of water quality associated with agricultural drainage return flows at internal Delta locations based DWR's Bulletin 123 (1967) are shown in Table 4.4.

Table 4.3: Constant Nutrient Data at Sacramento and San Joaquin Rivers and Martinez.

Parameter	Sacramento River Input (mg/L)	Martinez (mg/L)	San Joaquin River (mg/L)
Organic nitrogen as N	0.2	0.2	0.5
Ammonia as N	0.1	0.05	-[1]
Nitrite as N	0.01	0.01	0.20
Nitrate as N	0.1	0.1	1.70
Organic Phosphorus as P	0.01	0.01	0.10
Phosphate as P	0.03	0.03	0.15

1. Ammonia data for the San Joaquin River is shown in Table 4.2.

Table 4.4: Nutrient Data for Delta Agriculture Drainage.

Parameter	Value
Ammonia as N	0.31 mg/L
BOD	3.9 mg/L
Algae as chlorophyll	10.0 µg/L
Organic nitrogen as N	1.4 mg/L
Nitrite as N	0.02 mg/L
Nitrate as N	1.3 mg/L
Organic phosphorus as P	0.09 mg/L
Phosphate as P	0.4 mg/L

4.2.4 Climate Data

Air temperature, wetbulb temperature, wind speed, cloud cover, and atmospheric pressure are input for DSM2 simulation of water temperature in the Delta channels. Data at hourly intervals were available only at two stations in the Delta – at Sacramento and Stockton airports. Depending upon the location of interest in any given study, either data from the Sacramento airport or the Stockton airport may be used.

Hourly data was available from the National Climatic Data Center for the period of 1997-2000. The historical values for a given year were assigned to year in the planning studies based upon Table 4.5 by the same criteria as was done with water temperature and DO in Table 4.1. These data are shown in Figures 4.4a and 4.4b for air temperature and Figures 4.5a and 4.5b for wetbulb temperature.

Table 4.5: Assignment of Historical Data to Planning Year for Climate Data.

Planning Year	Historical Year
1974	1998
1975	1999
1976	**2000**
1977	1997
1978	1998
1979	1999
1980	**2000**
1981	1997
1982	1998
1983	1999
1984	**2000**
1985	1997
1986	1998
1987	1999
1988	**2000**
1989	1997
1990	1998
1991	1999

Leap years highlighted in bold.
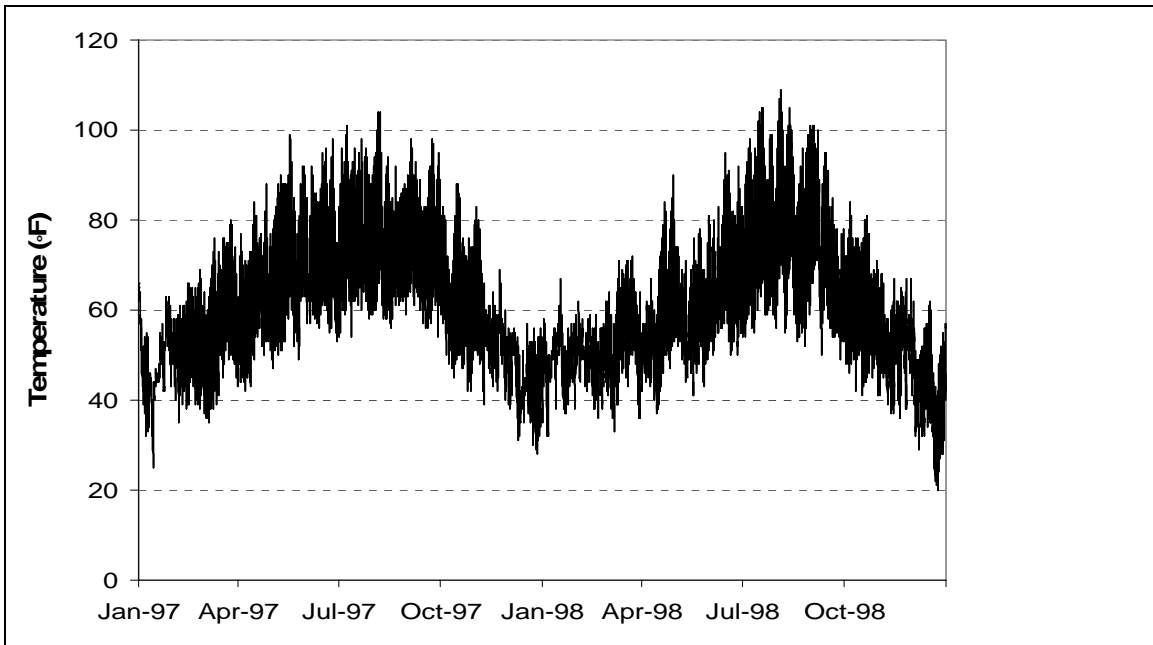
Figure 4.4a: Hourly Air Temperature at Stockton (1997-1998).
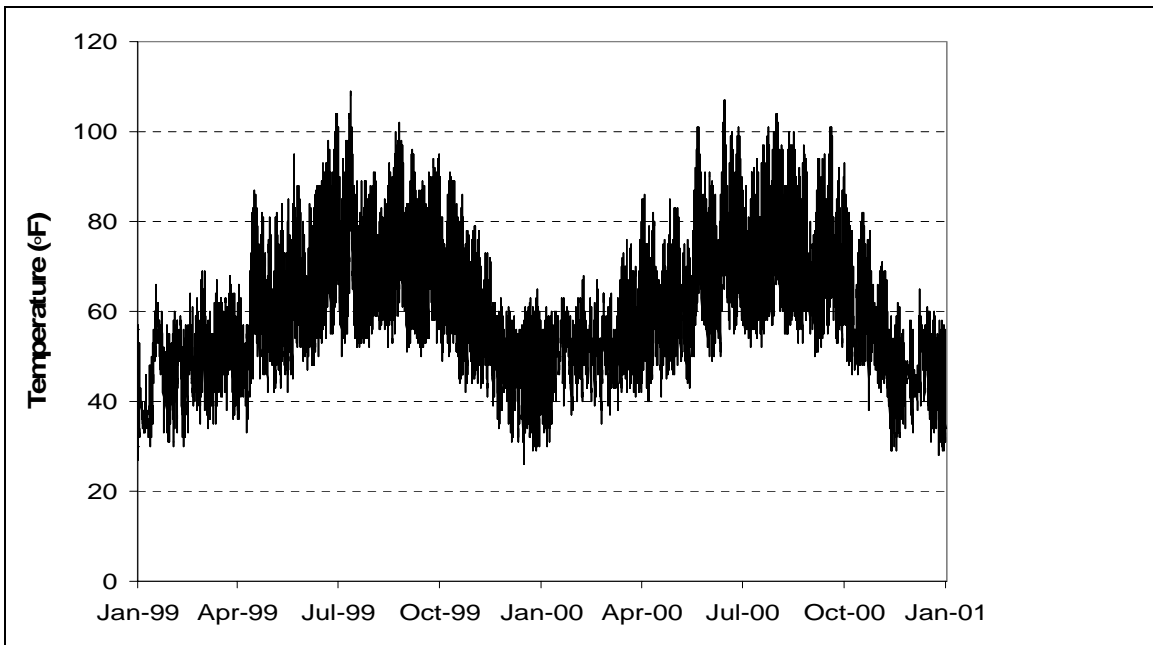
Figure 4.4b: Hourly Air Temperature at Stockton (1999-2000).
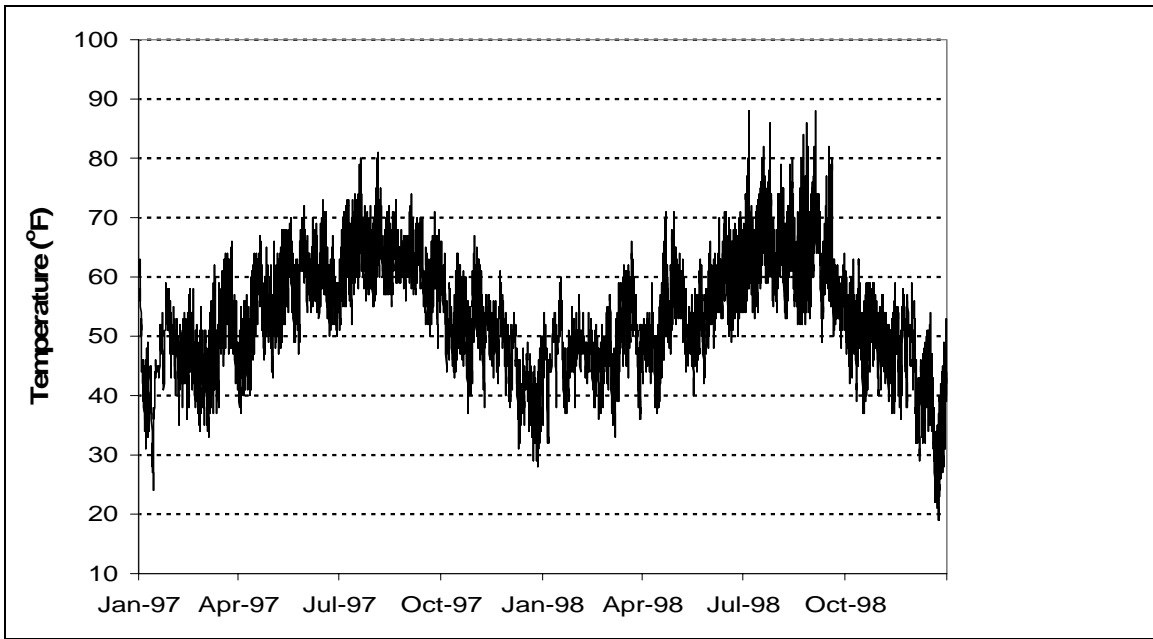
Figure 4.5a: Hourly Wetbulb Temperature at Stockton (1997-1998).
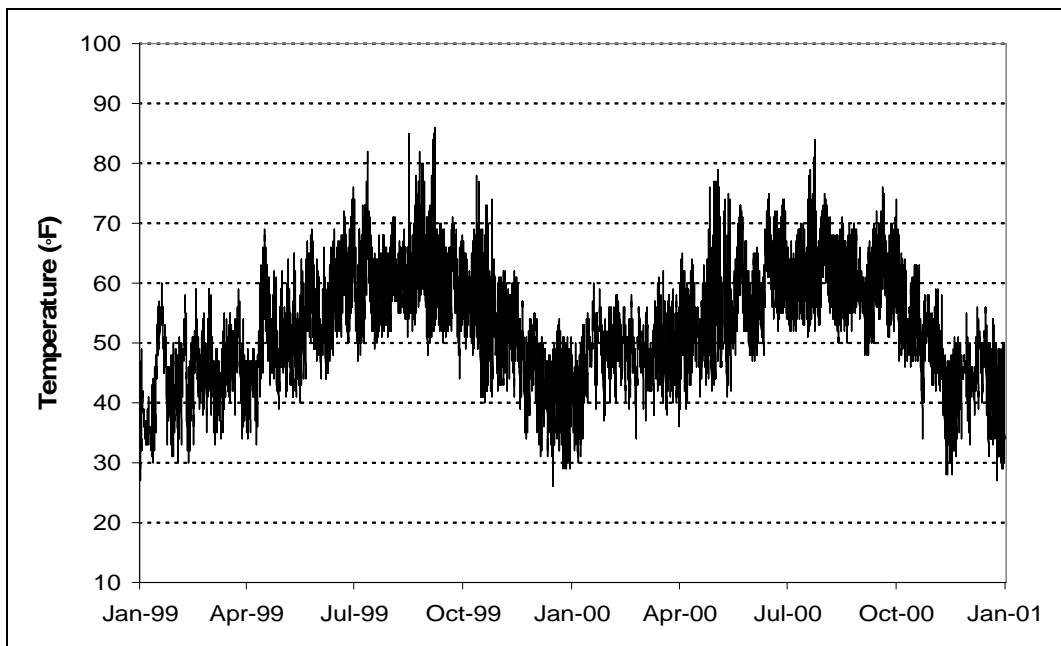
Figure 4.5b: Hourly Wetbulb Temperature at Stockton (1999-2000).

4.2.5 Stockton Regional Wastewater Control Facility Effluent Data

Data on effluent flows from the City of Stockton's Regional Wastewater Control Facility (RWCF) were obtained from the City of Stockton Municipal Utilities Department (Huber, 2001). Flow and temperature data were available on a daily basis, and organic nitrogen, nitrite nitrogen, and nitrate nitrogen data were available on weekly intervals. These data were used to generate average monthly estimates. Monthly average estimates of ammonia and BOD were based on 1987-1995 monthly data reported by Jones and Stokes (1998). Table 4.6 presents the resulting data used in simulating DO in DSM2 from the various sources. In addition, fixed values for the entire planning period were used for chlorophyll, phosphate, organic phosphorus, and DO based on limited data from 1999. These values were $40\,\mu g/L$, 0.05 mg/L, 0.35 mg/L, and 7.5 mg/L respectively. Because much of these data were derived from different sources, and inevitable loss of some important daily or even seasonal variations due to different averaging processes, the data in the present form should be used with discretion. Depending upon the geographical location of a particular project, these data may need to be recomputed. For example, for the studies in the San Joaquin River near the Stockton Deep Water Ship Channel, these data should be further refined.

Table 4.6: Generated Stockton RWCF Effluent Data.

Month	Organic-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	Ammonia-N (mg/L)	BOD (mg/L)	Temp (ºC)	Flow (cfs)
Jan	4.5	0.84	0.12	16.6	14	11.2	57
Feb	4.4	1.95	0.17	16.5	16	13.5	58
Mar	4.8	3.21	0.36	11.8	14	16.1	47
Apr	3.7	8.26	0.21	4.8	9	19.5	48
May	3.6	6.50	0.08	2.4	7	21.6	44
June	3.0	3.80	0.03	1.6	6	25.7	45
July	2.9	1.21	0.01	1.5	5	26.2	43
Aug	3.5	0.38	0.07	5.6	6	25.9	51
Sept	4.1	0.32	0.08	12.5	9	24	46
Oct	3.9	0.29	0.08	16.1	9	19.1	44
Nov	4.4	0.31	0.09	16.0	13	13.5	53
Dec	4.3	0.47	0.15	15.0	14	11	58

4.3 Resulting Input Data for DSM2 Simulation of DO in Planning Studies

4.3.1 San Joaquin River at Vernalis

Since continuous data were not available for the San Joaquin River at Vernalis, hourly values of DO and temperature available from the nearby station at Mossdale (RSAN087) were used to approximate these quantities for the boundary inflow at Vernalis. Since the flows at Vernalis are

primarily unidirectional, and the hydraulic residence time is relatively short, this assumption seems appropriate. These data, available in the IEP web site from 1984 to the present, are plotted in Figures 4.6a and 4.7a for the period 1984-1991. As described earlier, for the missing data during 1984-1991, and for 1974-1983, daily values obtained by averaging hourly values of 1997-2000 were used (Figures 4.6b and 4.7b, and Table 4.1).
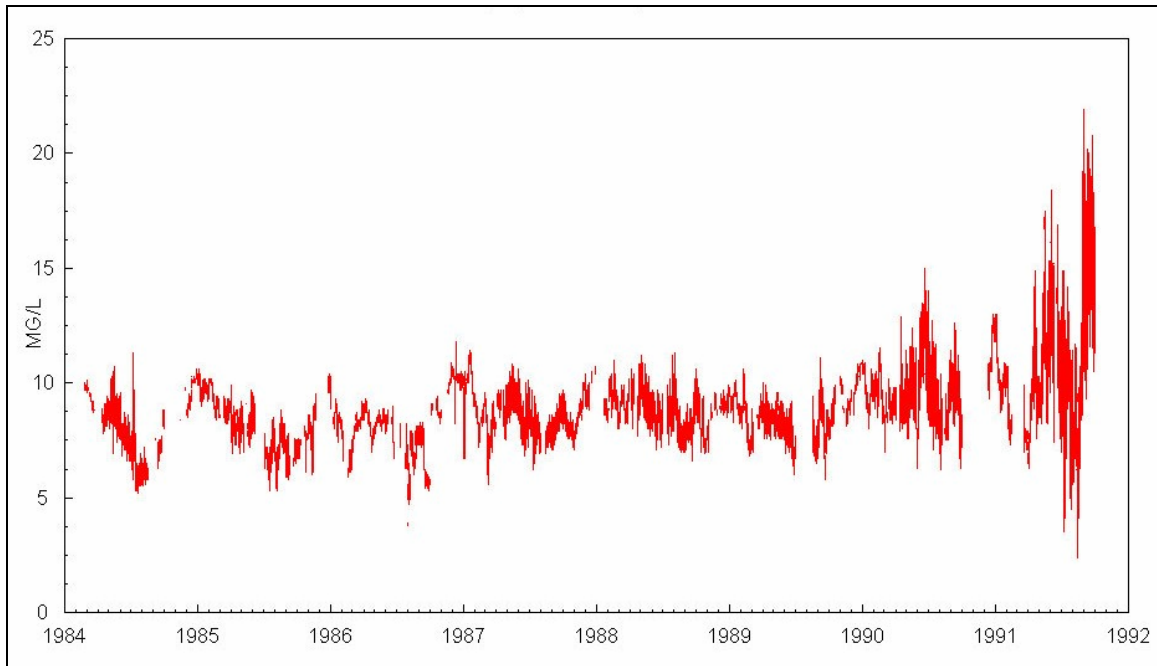
**Figure 4.6a: Hourly Dissolved Oxygen at Mossdale used as
Vernalis Bondary Condition (1984-1991).**

Figure 4.6b: Generated Daily Dissolved Oxygen at Vernalis (1975-1984).
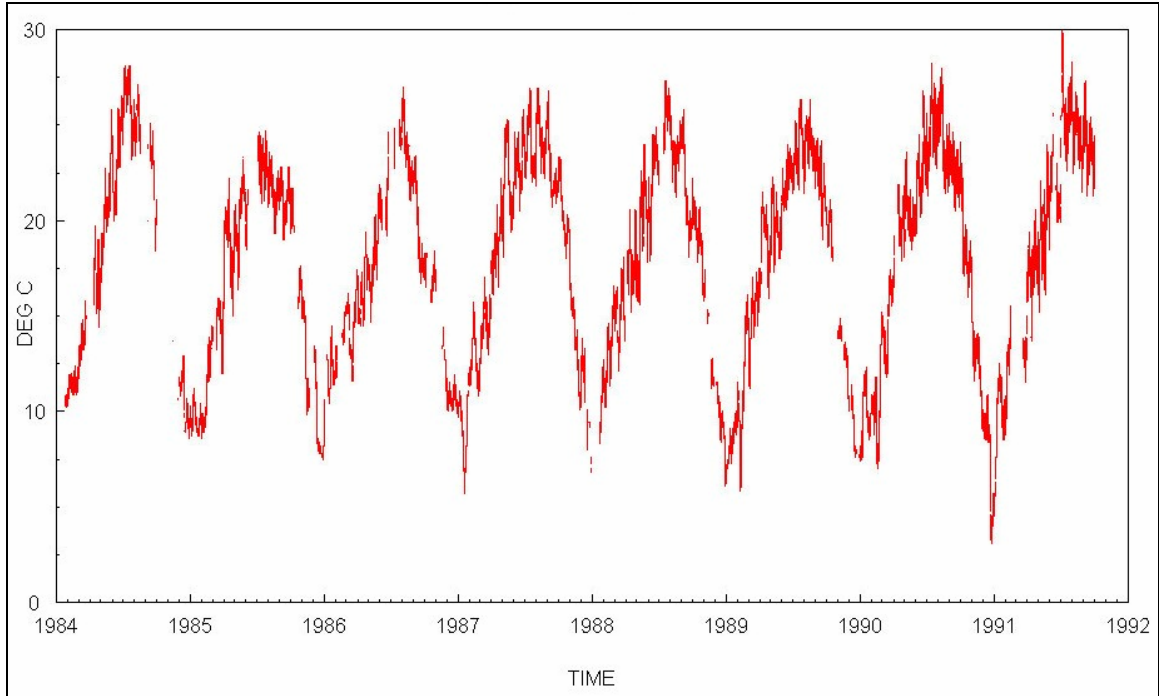
**Figure 4.7a: Hourly Temperature at Mossdale used as
Vernalis Boundary Condition (1984-1991).**
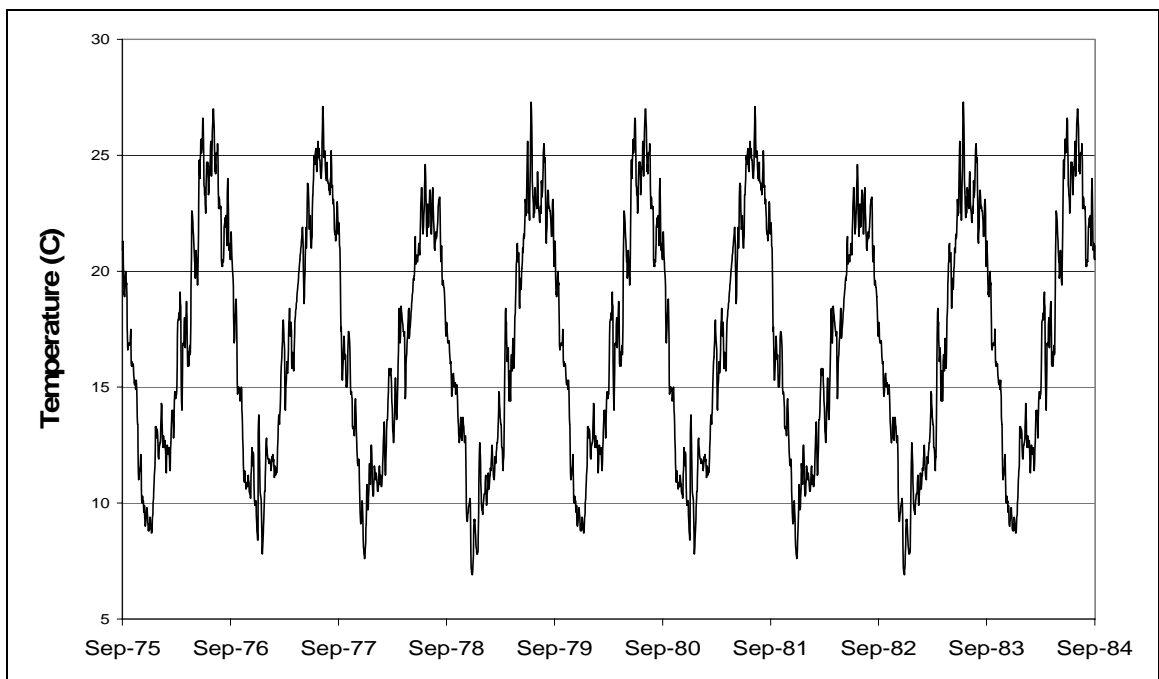
Figure 4.7b: Generated Daily Temperature at Vernalis (1975-1984).

4.3.2 Sacramento River at Freeport

As described in Section 4.2.2, daily average DO and water temperature data for the Sacramento River boundary was generated by averaging hourly data at Sacramento River at Freeport (RSAC142). These data were based on the available data from 1999 to 2001 (Figures 4.8 and 4.9).
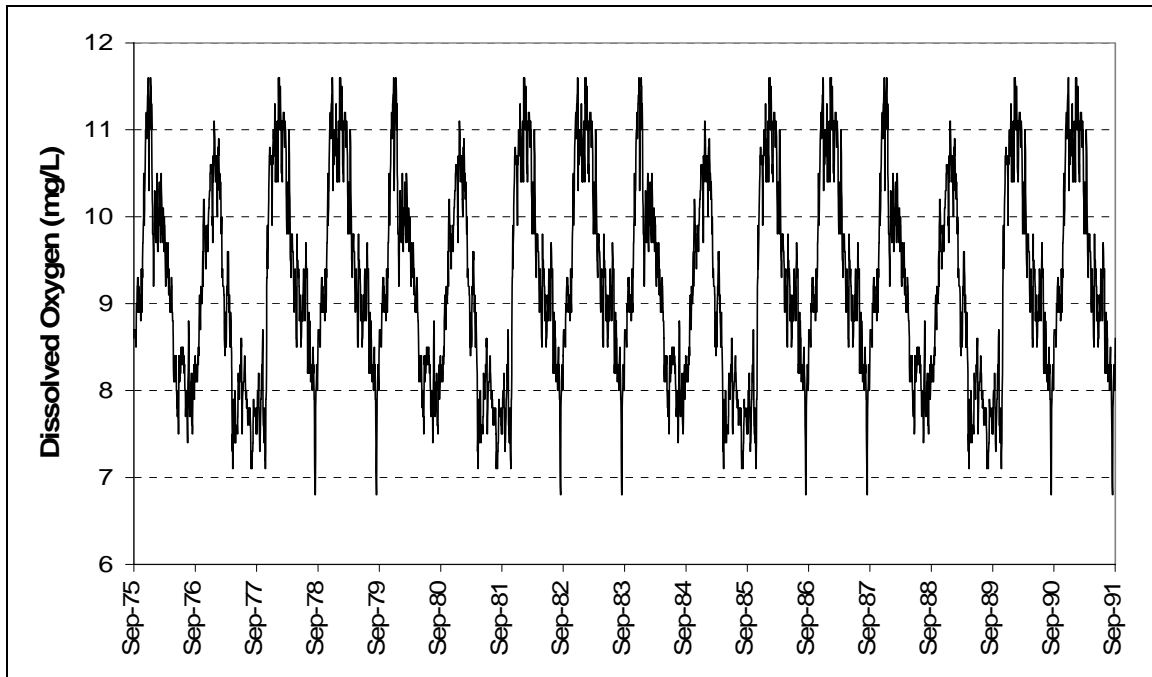
Figure 4.8: Generated Daily Dissolved Oxygen at Sacramento River, Freeport (1975-1991).
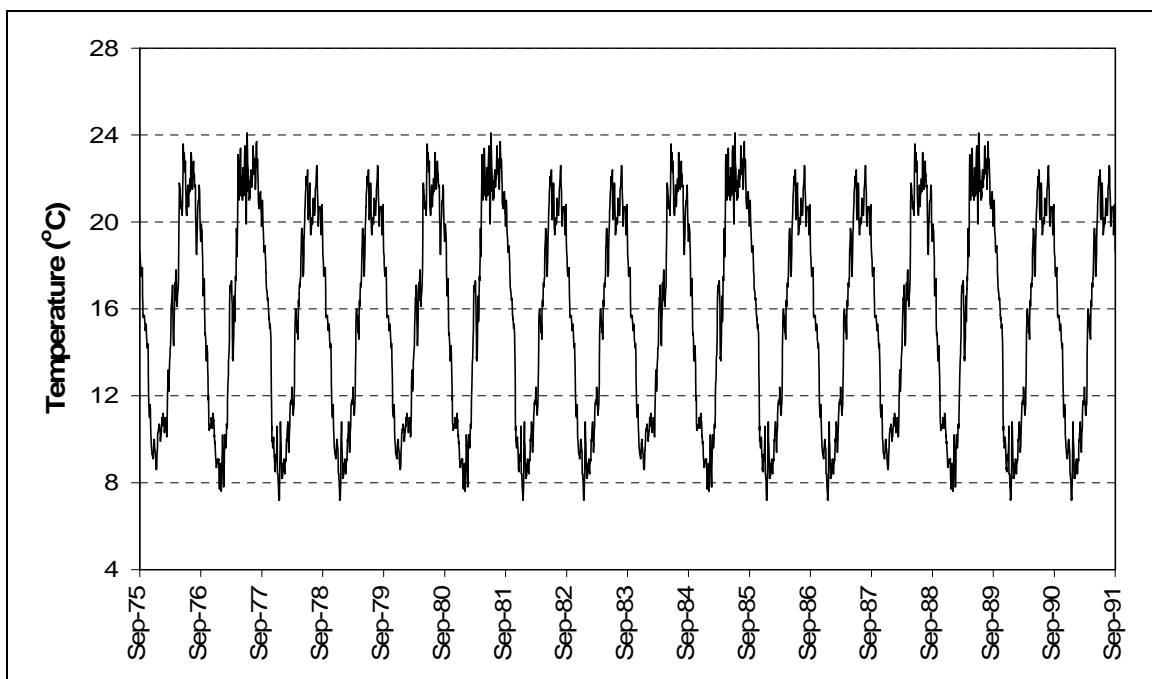
Figure 4.9: Generated Daily Temperature at Sacramento River, Freeport (1975-1991).

4.3.3 Martinez

Hourly DO and water temperature at Martinez (RSAC054), available from 1984 onwards, was used for the downstream boundary (Figures 4.10 and 4.12). As explained in Section 4.2.2, for the data missing during that period and for the entire 1974-1983 period, daily average values computed from 1997-2000 were generated both for DO and temperature (Figures 4.11 and 4.13).
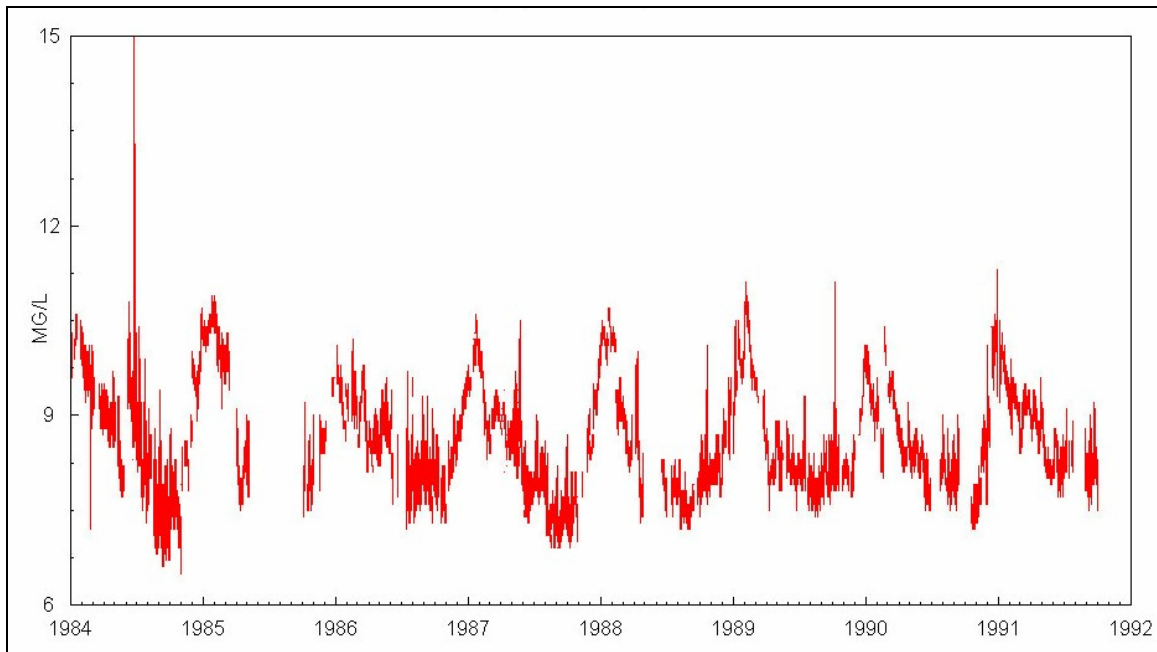
Figure 4.10: Hourly Dissolved Oxygen at Martinez (1984-1991).
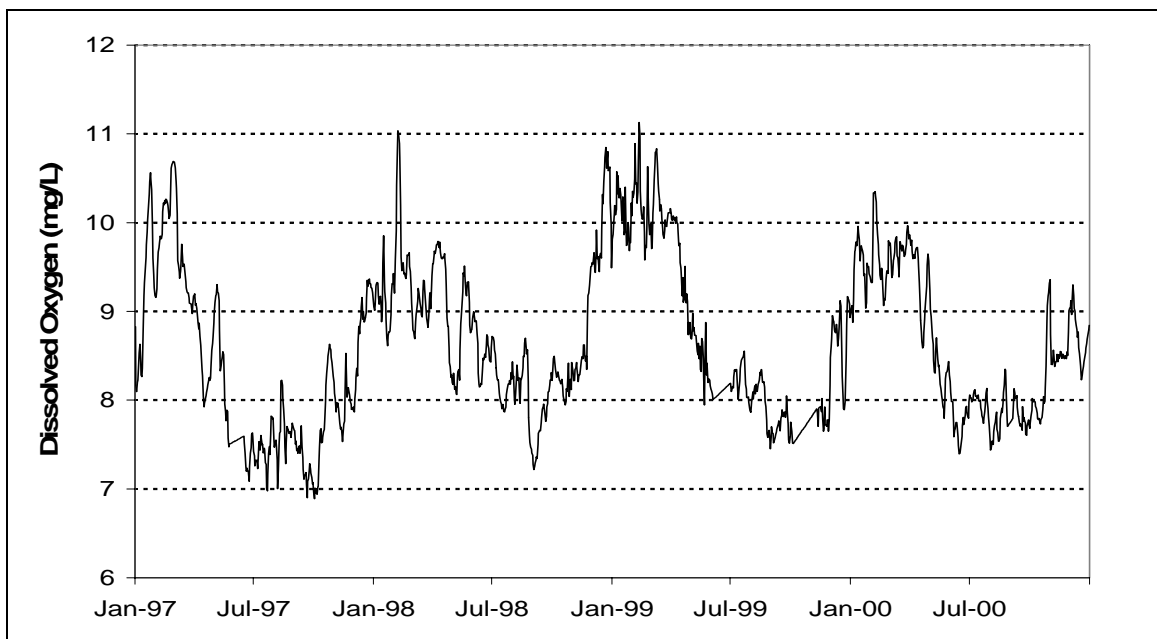
Figure 4.11: Generated Daily Dissolved Oxygen at Martinez used for the Period 1975-1983.
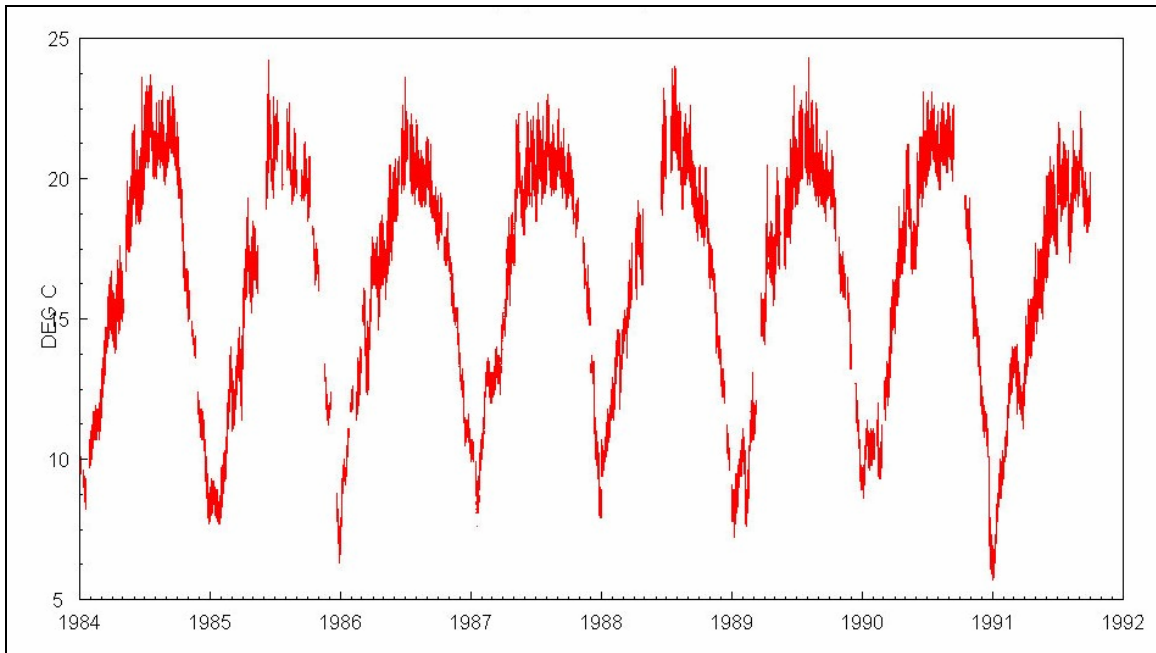
Figure 4.12: Hourly Temperature at Martinez (1984-1991).
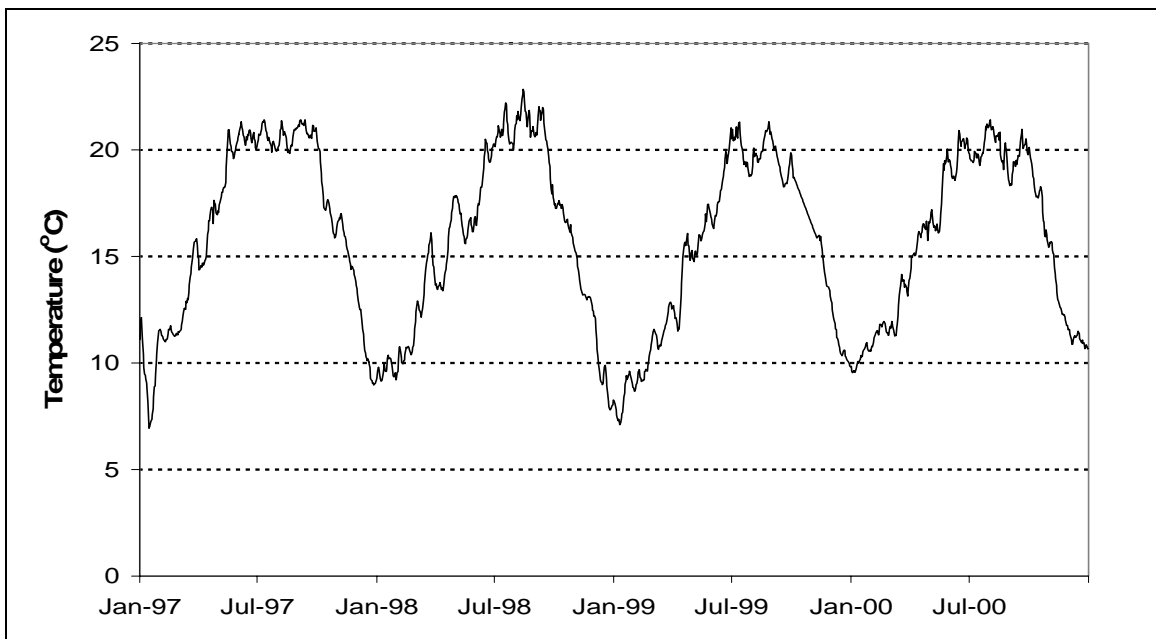
Figure 4.13: Generated Daily Temperature at Martinez used for the Period 1975-1983.

4.4 Conclusions

The current efforts to develop the planning study data series for DO and temperature simulations provide an important milestone. Considering the extent of missing data, it is expected that further data refinement will continue. In using the data in the present form, careful consideration should be made based on the geographical location and the nature of the study. For the preliminary assessments of the DO and temperature impact studies, these data sets should be appropriate in most cases.

For the future updates, grab samples at biweekly or monthly intervals collected at several locations in the Delta since 1975 can be utilized to provide an approximate monthly variation of nutrient data.

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Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 5:
Calculating Net Delta Outflow Using CALSIM II and DSM2

Author: Jamie Anderson

5 Calculating Net Delta Outflow Using CALSIM II and DSM2

5.1 Introduction

This chapter describes methods for computing Net Delta Outflow (NDO) using inputs or simulation results from CALSIM II and DSM2. CALSIM II is an application of the California Department of Water Resources' (DWR) and U. S. Bureau of Reclamation's (USBR) water resources operations model CALSIM of the State Water Project and Central Valley Project. In other words, CALSIM II is the specific version of the CALSIM model. DSM2 is DWR's one-dimensional unsteady flow and water quality model of the Sacramento-San Joaquin Delta.

The Sacramento-San Joaquin Delta is 738,000 acres with freshwater inflows from the Sacramento, San Joaquin, Mokelumne, Cosumnes, and Calaveras Rivers and tidal brackish water inflows from San Francisco Bay (DWR, 1995) (Figure 5.1). Net Delta Outflow is an indication of how much net flow leaves the Delta, typically considered as the net flow at Martinez or Chipps Island. NDO is difficult to measure directly at either Martinez or Chipps Island, so NDO is often estimated by either summing flows in several channels that represent total outflows, or by computing the mass balance between inflows, exports, and consumptive use in the Delta. This chapter documents how NDO is represented in CALSIM II, and how NDO can be computed from DSM2 inputs and simulation results.

5.2 NDO Computations in CALSIM II

NDO is computed in CALSIM II by computing a flow balance between channel flows, precipitation, exports and Delta Consumptive Use (DCU). The values for the flow balance are provided by CALSIM output at selected channel arcs (CALSIM flow paths).   In CALSIM nomenclature, each channel arc is identified by a letter and a number. The following naming convention is used for the CALSIM channel arcs:

- ❑ C###: Channel flow, e.g. C169 represents Sacramento River inflow to the Delta
- ❑ D###: Delivery (export) or consumptive use, e.g. D419 represents SWP exports
- ❑ I###: Inflow/Precipitation, e.g. I404 represents one of four Delta precipitation arcs

The Delta portion of the CALSIM II grid is shown in Figure 5.2. Descriptions of the CALSIM II arcs that are used in the NDO computations are presented in Table 5.1.

Area of Detail

Sacramento River

● Sacramento

Vallejo

Cosumnes River

North Bay Aqueduct

Yolo Bypass

Mokelumne River

Agricultural
Diversions and
Return Flows
(250+ locations)

Calaveras River

Chipps Island

Martinez

● Stockton

Contra Costa Canal

Banks Pumping
Plant (SWP)

Tracy Pumping
Plant (CVP)

San Joaquin
River

Legend

Inflows

Exports

Tidal Flows
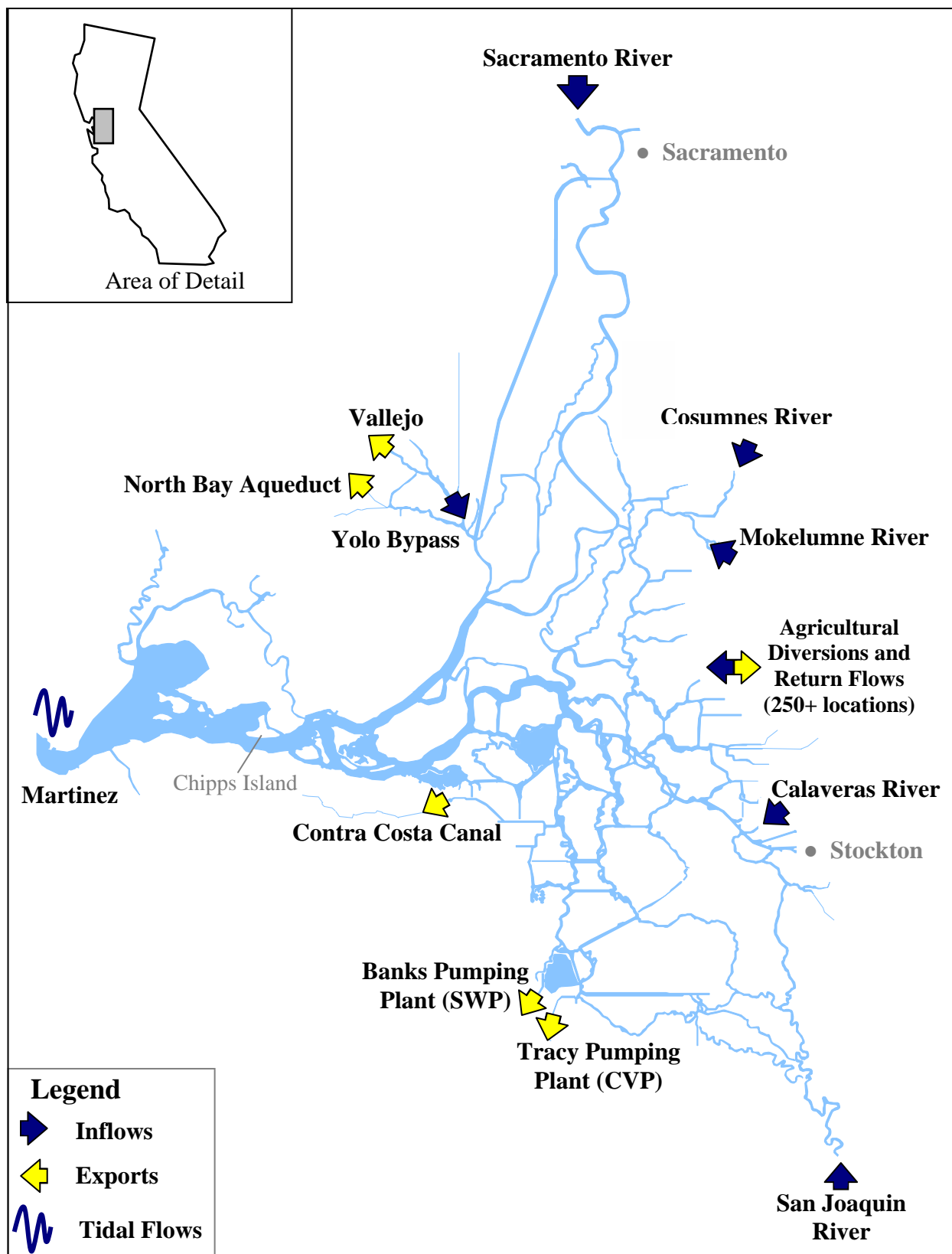
Figure 5.1: Sacramento-San Joaquin Delta.

There are two main methods for computing NDO based on CALSIMII output. The first method sums the various Delta outflow requirements using the following equation:

$$NDO_{CALSIM} = C407 + D407 \qquad \text{[Eqn. 5-1]}$$

where,
D407 = Delta outflow requirements under D1641, and
C407 = Additional delta outflow due to other constraints such as import/export ratios.

Alternatively, NDO can be computed by using the individual CALSIM II arcs to compute a flow balance (see Table 5.1 for definition of each CALSIM II arc):

$$NDO_{CALSIM} = \underbrace{C157 + C169 + C504 + C508 + C639}_{\text{River Inflows}} + \underbrace{I406}_{\text{Marsh Creek}} + \underbrace{I404 + I410 + I412 + I413}_{\text{Delta Precipitation}}$$

$$\underbrace{- D403A - D403B - D408 - D418 - D419}_{\text{Exports}} - \underbrace{D404 - D410 - D412 - D413}_{\text{Delta Consumptive Use}} \qquad \text{[Eqn. 5-2]}$$

Table 5.1: CALSIM II Values Used to Compute NDO.

CALSIM II Arc	Sign in NDO computation	Description
Sum of Delta Outflows		
C407	+	Additional delta outflow due to other constraints such as import/export ratios
D407	+	Delta outflow requirements under D1641
Inflows minus Exports		
C157	+	Yolo Bypass inflow to the Delta
C169	+	Sacramento River inflow to the Delta
C504	+	Mokelumne and Cosumnes rivers combined inflow to the Delta
C508	+	Calaveras River inflow to the Delta
C639	+	San Joaquin River inflow to the Delta
I 406	+	Marsh Creek inflow to the Delta
I404, I410 I412, I413	+	Delta Precipitation
D403A	-	Vallejo
D403B	-	North Bay Aqueduct
D408	-	Contra Costa Exports
D418	-	CVP Exports
D419	-	SWP Exports
D404, D410 D412, D413	-	Delta Consumptive Use
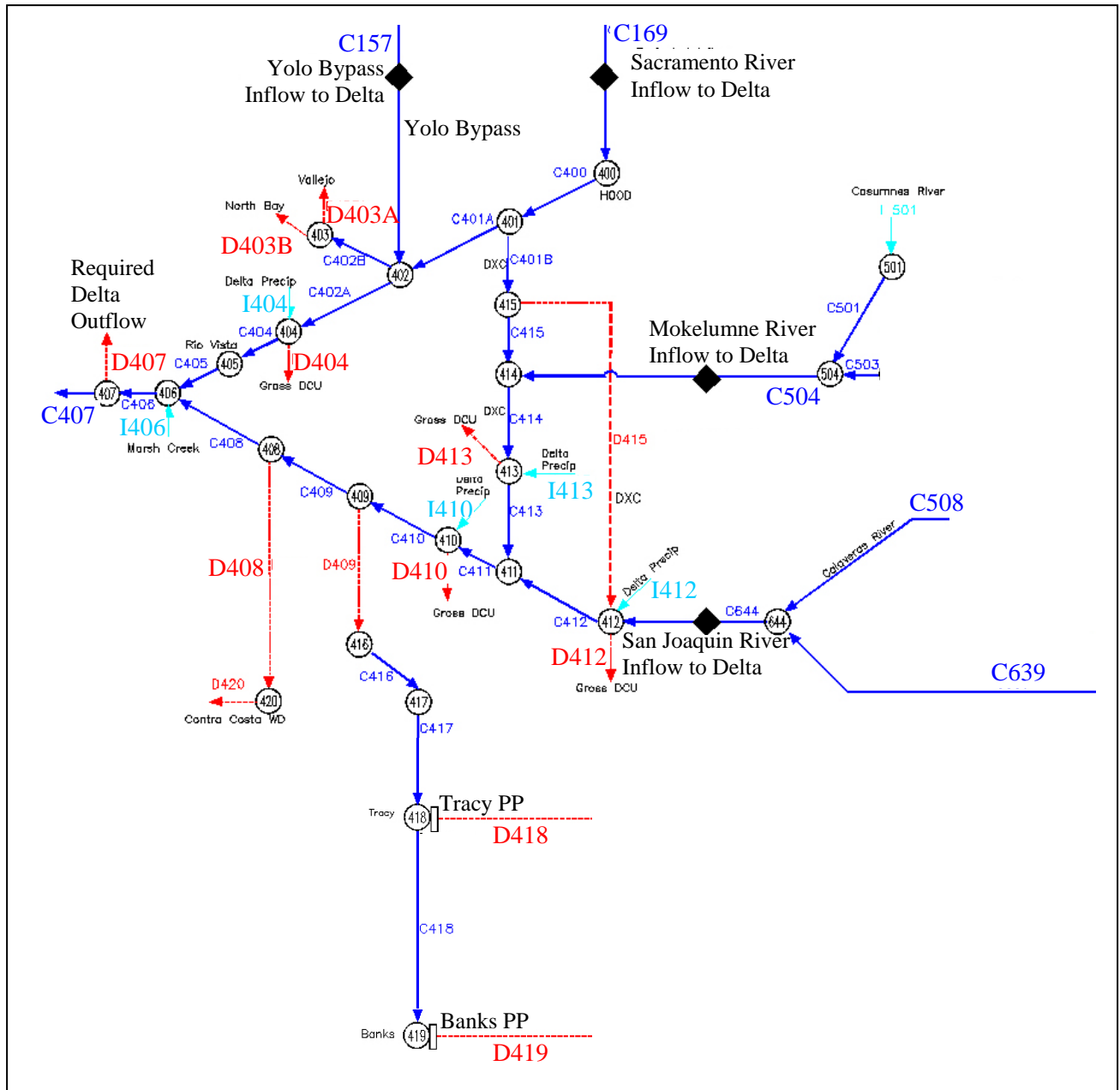
Figure 5.2: Delta Portion of the CALSIM II Grid.

5.3 NDO Computations Using DSM2

This section presents methods for computing NDO using either DSM2 boundary input values or simulation results from DSM2.

5.3.1 NDO Computations Using DSM2 Inputs

NDO can be computed as a mass balance of the boundary inflows and exports specified as inputs for a DSM2 simulation. The mass balance NDO is computed by summing inflows and subtracting total exports and total Delta Island Consumptive Use (DICU):

$$NDO_{DSM2} = \sum Inflows_{DSM2} - \sum Exports_{DSM2} - DICU_{DSM2} \qquad \text{[Eqn. 5-3]}$$

Equation 5-3 can be rewritten referring to the DSM2 node numbers associated with each inflow and export (see Table 5.2 for definitions of each node number):

$$NDO_{DSM2} = \underbrace{Q_{Node\,330} + Q_{Node\,17} + Q_{Node\,257} + Q_{Node\,21} + Q_{Node\,316}}_{DSM2\ Inflows}$$

$$\underbrace{-Q_{Node\,72} - Q_{Node\,118} - Q_{Node\,206} - Q_{Node\,273} - Q_{Node\,320}}_{DSM2\ Exports} - DICU_{DSM2} \qquad \text{[Eqn. 5-4]}$$

Note that total DICU includes consumptive use for Byron Bethany Irrigation District (BBID).

Table 5.2: DSM2 Input Values Used to Compute NDO.

DSM2 Node	DSM2 Name	Sign in NDO computation	Description
Inflows			
17	sjr	+	San Joaquin River inflow to the Delta
21	cal	+	Calaveras River inflow to the Delta
257	eastside	+	Mokelumne and Cosumnes combined inflow to the Delta
316	yolo	+	Yolo Bypass inflow to the Delta
330	sac	+	Sacramento River inflow to the Delta
Exports			
72	swp,clfct	-	SWP Exports
118	cvp	-	CVP Exports
206	ccc	-	Contra Costa Exports
273	nba	-	North Bay Aqueduct
320	vallejo	-	Vallejo

5.3.2 NDO Computations Using DSM2 Outputs

NDO can be estimated three different ways by computing tidally averaged simulated flows from DSM2 at selected locations that represent all outflow sources from the Delta (Figure 5.3):

- ❑ Martinez (DSM2 channel 441) (Figure 5.4)
- ❑ Chipps Island and Montezuma Slough (DSM2 channels 437, 442, and 511) (Figure 5.5)
- ❑ (Rio Vista, 3-Mile Slough, Jersey Point, and Dutch Slough (DSM2 channels 430, 309, 83, and 274) (Figure 5.6)

NDO-Martinez

NDO can be estimated from the tidally averaged flow at Martinez by tidally averaging DSM2 simulated flow results at channel 441 (Figure 5.4):

$$NDO_{DSM\,2} = \underbrace{Q_{Channel\,441}}_{Martinez} \qquad \text{[Eqn. 5-5]}$$

NDO-Chipps Island

NDO can be estimated by summing tidally averaged flows at three channels near Chipps Island: South of Chipps Island (channel 437), North of Chipps Island (channel 442) and Montezuma Slough (channel 511) (Figure 5.5):

$$NDO_{DSM\,2} = \underbrace{Q_{Channel\,437}}_{Chipps\,Is\,South} + \underbrace{Q_{Channel\,442}}_{Chipps\,Is\,North} + \underbrace{Q_{Channel\,511}}_{Montezuma\,Sl} \qquad \text{[Eqn. 5-6]}$$

NDO-Rio Vista/Jersey Point

NDO can be estimated by summing tidally averaged flows at four channels that flow into the Delta: the Sacramento River at Rio Vista (channel 430), 3-Mile Slough (channel 309), San Joaquin River at Jersey Point (channel 83), and Dutch Slough (channel 274) (Figure 5.6):

$$NDO_{DSM\,2} = \underbrace{Q_{Channel\,430}}_{Sac\,R\,@\,Rio\,Vista} + \underbrace{Q_{Channel\,309}}_{3-Mile\,Slough} + \underbrace{Q_{Channel\,83}}_{SJR\,@\,Jersey\,Po\text{int}} + \underbrace{Q_{Channel\,274}}_{Dutch\,Slough} \qquad \text{[Eqn. 5-7]}$$

The USGS maintains UVM (Ultrasonic Velocity Meter) flow monitoring sites at these four locations (IEP, 2004). Thus NDO computed using Eqn. 5-7 for a DSM2 historical simulation can be compared to field measurements.
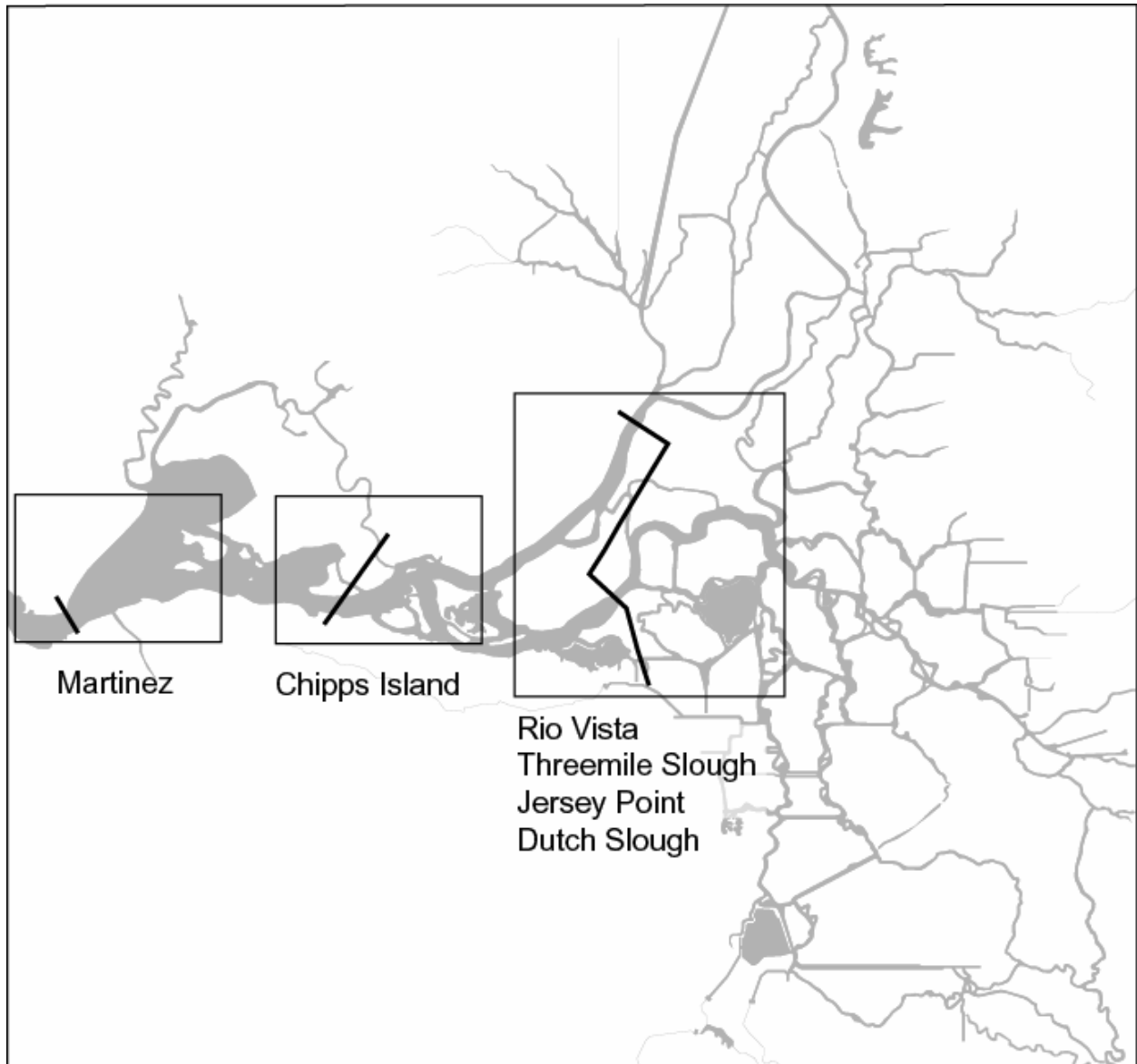
Figure 5.3: DSM2 Net Delta Outflow Estimation Locations.
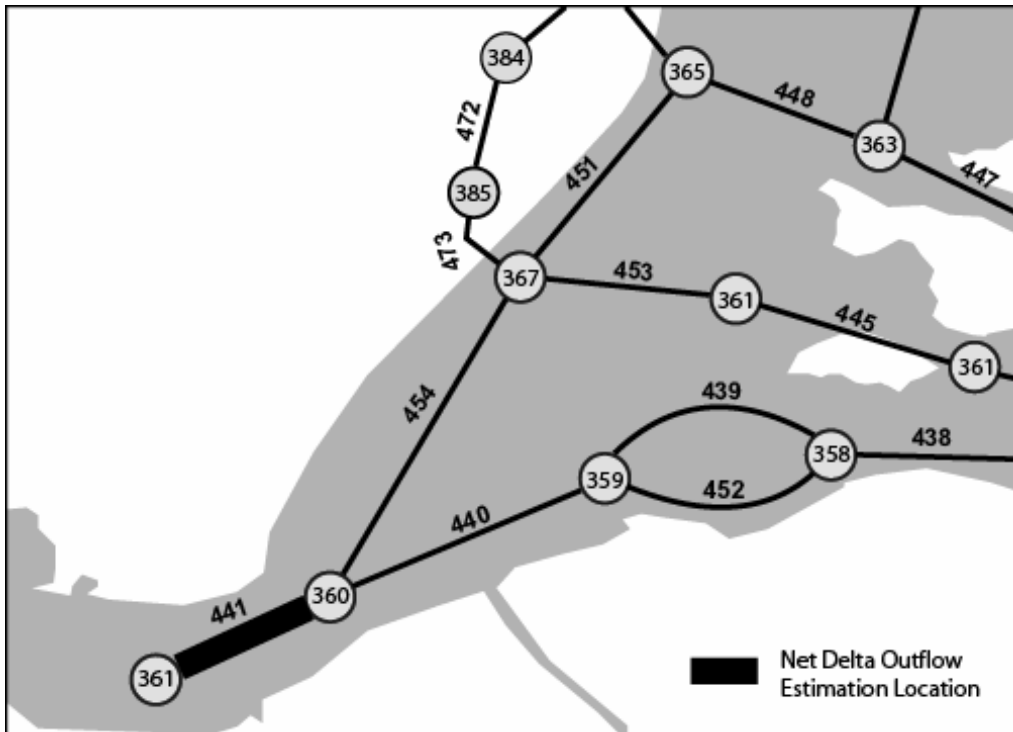
Figure 5.4: Martinez NDO Estimation Location on the DSM2 Grid.
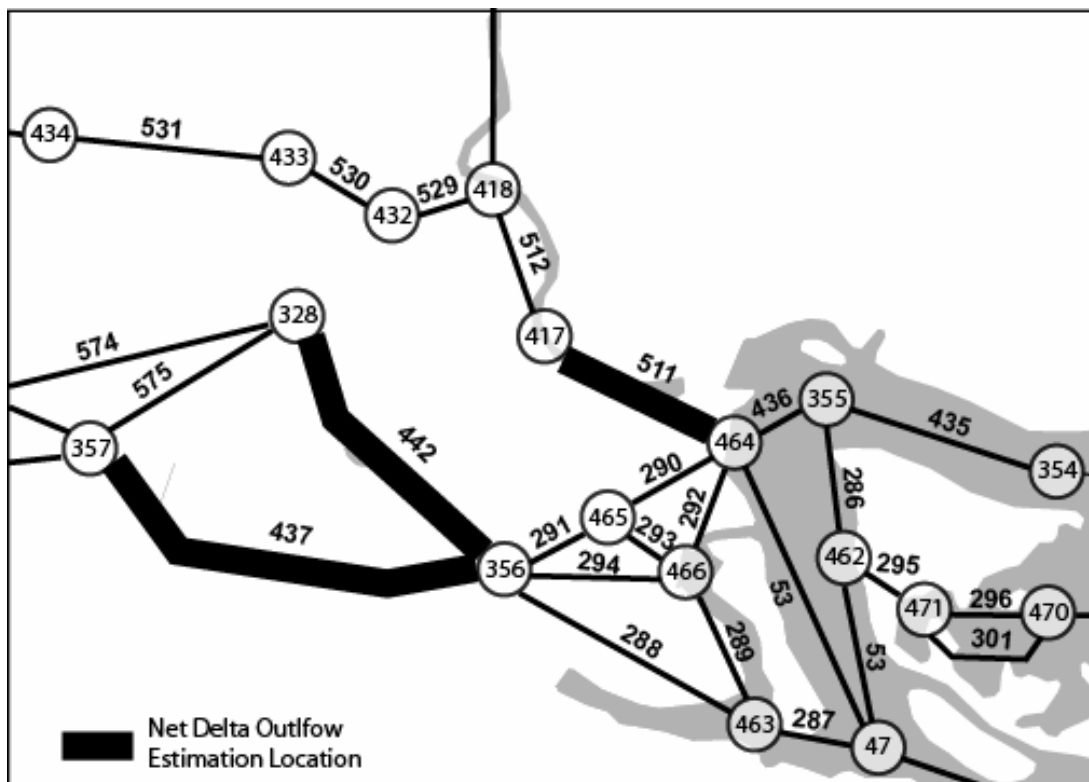
Figure 5.5: Chipps Island NDO Estimation Locations on the DSM2 Grid.
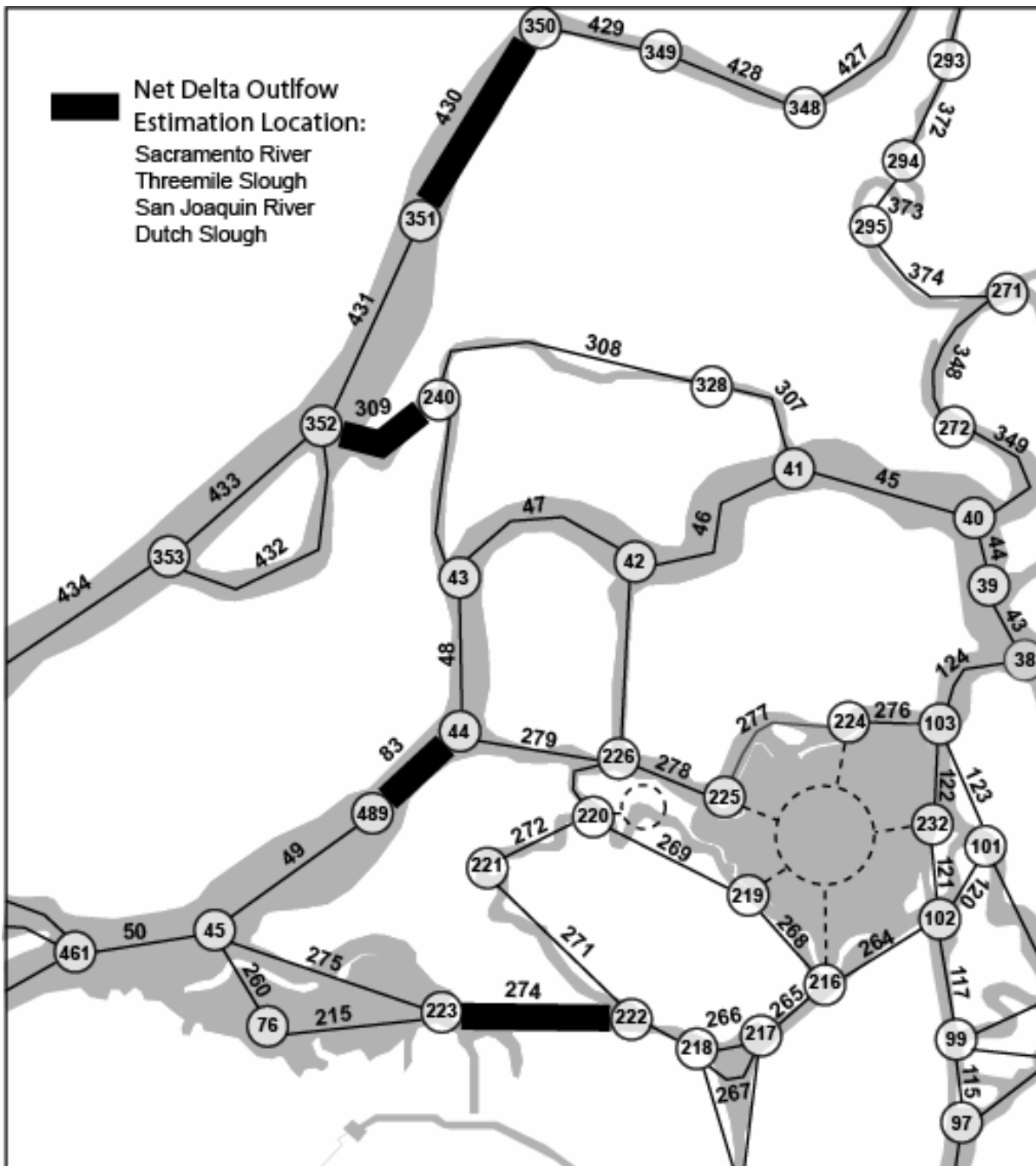
Figure 5.6: Rio Vista / Jersey Point NDO Estimation Locations on the DSM2 Grid.

5.3.3 Differences in NDO Computations Using DSM2 Inputs or Outputs

Steady state DSM2 simulations have confirmed that NDO computed from Equations 5-4 through 5-7 will produce identical results (see Chapter 6; Anderson, 2004). These steady state results confirm that:

❑ DSM2 conserves mass (also see Nader, 1993)

❑ Parameters used in Equations 5-4 through 5-7 represent all Delta outflows for NDO computations

Although NDO computed from Equations 5-4 through 5-7 will produce identical results for steady state DSM2 simulations, these equations will not produce identical results for DSM2 simulations that include the spring-neap tidal cycle. Typically spring-neap tidal cycles are represented in DSM2 historical simulations that use historical tidal data at Martinez and in DSM2 planning simulations that use an Adjusted Astronomical Tide boundary condition at Martinez. Sample monthly NDO computations using the four DSM2 input and output NDO equations (Eqn. 5-4 through Eqn. 5-7) are shown in Figure 5.7 for the South Delta Improvement Project's 2020 Integrated scenario which utilized an Adjusted Astronomical Tide. Figure 5.8 illustrates differences between the NDO computations using DSM2 outputs (Eqns. 5-5 through 5-7) and NDO computed from DSM2 inputs (Eqn. 5-4) which ranged from ± 2,500 cfs for Oct 75-Oct 81 2020 Integrated scenario data. One factor that contributes to the differences in NDO estimates based on DSM2 outputs compared to DSM2 inputs is that the mass balance computation based on DSM2 inputs (Eqn. 5-4) does not account for complex tidal dynamics.

Differences in NDO computations using DSM2 inputs and outputs for simulations that include spring-neap tidal cycles and dynamic inflow boundary conditions are due to several complex dynamics of unsteady flows in tidal systems including:

❑ Filling and draining of the Delta during spring-neap cycles,

❑ Travel time of transient Delta flows,

❑ Ability of the data processing technique used to compute NDO parameters to reflect tidal dynamics (monthly average, 24.75 hour running average, Godin filter, etc.) (see Chapter 6; Anderson, 2004), and

❑ Seasonal pattern of stage at Martinez, typically lower in winter and spring and higher in summer and fall (see Chapter 6; Anderson, 2004).

Note that similar discrepancies between NDO estimates have also been noted in DAYFLOW (IEP, 2004). DAYFLOW estimates NDO based on a mass balance of inflows and exports (analogous to Eqn. 5-3 and Eqn. 5-4). This mass balance is referred to as the Net Delta Outflow Index (NDOI). DAYFLOW documentation indicates that differences in NDOI values compared with NDO estimates based on USGS field data at Rio Vista, 3-Mile Slough, Jersey Point and Dutch Slough (analogous to Eqn. 5-7) are due to filling and draining of the Delta.
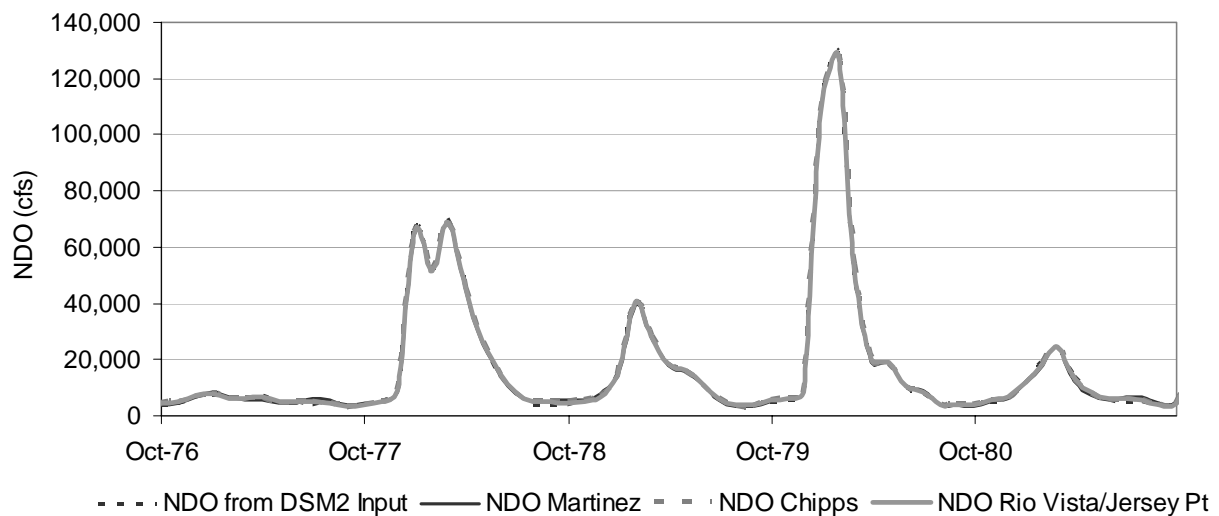
Figure 5.7: Monthly Averaged NDO Computed from DSM2 Inputs and Outputs for the SDIP 2020 Integrated Scenario.

Note: The four time series are similar, thus making the separate lines hard to distinguish.
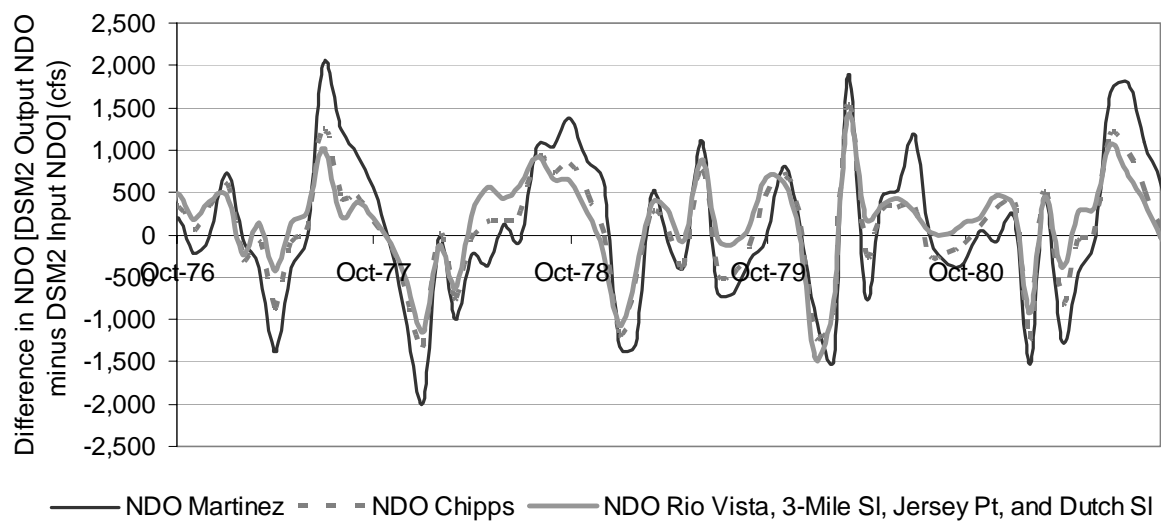
Figure 5.8: Difference in Monthly Averaged NDO (DSM2 Output NDO minus DSM2 Input NDO) for the SDIP 2020 Integrated Scenario.

5.4 Comparison of CALSIM II and DSM2 NDO Computations

For Quality Assurance/Quality Control (QAQC) purposes, it can be verified that the NDO in a DSM2 planning study matches the NDO from the CALSIM II simulation upon which the DSM2 study is based. This section compares NDO computed by CALSIM II (Eqns. 5-1 or 5-2) to NDO estimated from DSM2 inputs for planning studies (Eqns. 5-3 or 5-4). Parameters used in the NDO computations are discussed first, followed by a comparison of NDO computations for the two models.

5.4.1 CALSIM II Output Used Directly in DSM2 Planning Studies

For typical DSM2 planning studies, the channel inflows to the Delta (C157 Yolo Bypass, C169 Sacramento River, C504 Mokelumne and Cosumnes Rivers, C508 Calaveras River, and C639 San Joaquin River) and Delta exports (D403A Vallejo, D403B North Bay Aqueduct, D408 Contra Costa Exports, D418 CVP, and D419 SWP) used in the CALSIM II NDO calculations (Eqn. 5-2) are directly input into DSM2.

For some DSM2 planning studies, the monthly Sacramento River and San Joaquin River flows are smoothed to daily values to minimize numerical instabilities between months with large flow transitions. Monthly CALSIM II values for the San Joaquin River, CVP and SWP may also be converted to daily values to represent flows during the Vernalis Adaptive Management Plan (VAMP) period from April 15-May 15.

5.4.2 NDO Components not Included in Both CALSIM II and DSM2

In CALSIM II, inflow from Marsh Creek is included in the NDO computations (Eqn. 5-2), however this flow is typically not included in DSM2 planning studies. For the 2020 Integrated Scenario, the maximum flow in Marsh Creek was approximately 375 cfs.

5.4.3 DICU in CALSIM II and DSM2

Total Delta Island Consumptive Use (DICU) in CALSIM II is computed by summing the Delta Consumptive Use arcs and subtracting the precipitation inflow arcs as follows:

$$\mathrm{DICU_{CALSIM}} = \underbrace{\mathrm{D404 + D410 + DI412 + DI413}}_{\text{Delta Consumptive Use}} - \underbrace{\mathrm{I404 - I410 - I412 - I413}}_{\text{Delta Precipitation}} \qquad \text{[Eqn. 5-8]}$$

For consistency between CALSIM II and DSM2 planning studies, the total DICU in DSM2 is modeled as being mathematically equivalent to the DICU in CALSIM II:

$$\mathrm{DICU_{DSM2} = DICU_{CALSIM}} \qquad \text{[Eqn. 5-9]}$$

The distribution of DICU values used in DSM2 planning studies are determined by running DWR's DICU and Adjusted Delta Island Consumptive Use (ADICU) models using CALSIM II DICU as input (Mahadevan, 1995). Based on water year type, monthly average historical precipitation, monthly average historical pan evaporation and fixed values of land use for each DICU subarea, and a single Delta-wide irrigation efficiency value, the DICU model computes the historical irrigation diversions, seepage, and drainage (return flows) at each of the 257 DSM2 DICU locations (Figure 5.9). DWR's ADICU model then disaggregates the total Delta Consumptive Use from CALSIM II to these 257 locations by adjusting the historical patterns. Total DICU in DSM2 is computed by adding the irrigation diversions and seepage and subtracting the drainage (Eqn. 5-10). The total DICU computed from the irrigation diversions, seepage, and drainage computed from the DICU model will be mathematically equivalent to the DICU computed from CALSIM (Eqn. 5-9).

$$DICU_{DSM2} = \sum^{DSM\,2\,DICU\,Nodes} Irrigation\,Diversions + Seepage - Drainage \qquad \text{[Eqn. 5-10]}$$

Determine Total DICU from CALSIM

$$DICU_{CALSIM} = \underbrace{D404 + D410 + DI412 + DI413}_{\text{Delta Consumptive Use}} - \underbrace{I404 - I410 - I412 - I413}_{\text{Delta Precipitation}}$$

Historical Data Input to DWR's DICU Model

- ❑ Water year type
- ❑ Monthly average precipitation
- ❑ Monthly average pan evaporation
- ❑ Land use (varies by subarea but not with time)
- ❑ Irrigation efficiency (single Delta-wide value)

DWR's DICU Model

- ❑ At 257 Delta locations (DSM2 nodes) computes
  - – Irrigation Diversions
  - – Seepage
  - – Drainage (return flows)

- ❑ $DICU_{DSM2} = DICU_{CALSIM}$

- ❑ $DICU_{DSM2} = \sum^{DSM\,2\,DICU\,Nodes} Irrigation\,Diversions + Seepage - Drainage$

Figure 5.9: Computation of DICU for DSM2 based on CALSIM Results.

5.4.4 Comparing CALSIM II and DSM2 NDO

To verify that the NDO in a DSM2 planning study matches the NDO from the CALSIM II simulation upon which the DSM2 study is based (a typical QAQC procedure), the NDO from the DSM2 study can be compared to the NDO from the CALSIM II study with appropriate adjustments for parameters that are included in one model but not the other. The following equations compare DSM2 NDO to CALSIM II NDO with an adjustment to reflect Marsh Creek inflows that are considered in CALSIM II but not in DSM2:

$$NDO_{DSM2} = NDO_{CALSIM} - \underbrace{I406_{CALSIM}}_{Marsh\,Creek} \qquad \text{[Eqn. 5-11]}$$

Substituting Eqn. 5-3 into Eqn. 5-11 results in the following equation:

$$NDO_{CALSIM} = \sum Inflows_{DSM2} - \sum Exports_{DSM2} - DICU_{DSM2} + \underbrace{I406_{CALSIM}}_{Marsh\,Creek} \qquad \text{[Eqn. 5-12]}$$

Substituting Eqn. 5-4 into Eqn. 5-12 results in the following equation:

$$NDO_{CALSIM} = \underbrace{Q_{Node330} + Q_{Node17} + Q_{Node257} + Q_{Node21} + Q_{Node316}}_{DSM2\,Inflows} \qquad \text{[Eqn. 5-13]}$$

$$\underbrace{- Q_{Node72} - Q_{Node118} - Q_{Node206} - Q_{Node273} - Q_{Node320}}_{DSM2\,Exports} - DICU_{DSM2} + \underbrace{I406_{CALSIM}}_{Marsh\,Creek}$$

The comparison of CALSIM II and DSM2 NDO using Equation 5-13 will be equivalent if the CALSIM II outputs are used directly in DSM2. However monthly CALSIM II data are often modified in DSM2 to smooth flow transitions from month to month (typically Sacramento and San Joaquin River flows) or to represent flow and export adjustments during the VAMP period from April 15-May 15 (typically San Joaquin River flows, and CVP and SWP exports).

Depending on the technique used to modify the CALSIM II input from monthly to daily values, the CALSIM II and DSM2 NDO values may not be exactly the same. For example, a tension spline is often used in planning studies to smooth monthly Sacramento and San Joaquin River flows to daily values. The tension spline is conservative over the entire smoothing period (typically the 16-year planning study period), however the average values for any given month may not be identical to the monthly values from CALSIM II. Thus, monthly DSM2 NDO computations using the average of the daily smoothed values may not be identical to the CALSIM II NDO when comparing individual months, but the total NDO for the simulation period will be identical. For the 2020 Integrated Scenario which smoothed monthly flows to a

daily time step for the Sacramento River, the maximum difference in monthly NDO was approximately 135 cfs.

The techniques typically used to create daily time series to represent VAMP for San Joaquin River flows and CVP and SWP exports preserves the monthly average values at those locations. Thus monthly NDO computations using flow and export values that had been adjusted to represent the VAMP period would still be identical for CALSIM II and DSM2 if no other variables were modified.

5.5 Summary

Net Delta Outflow is an estimate of the net flow leaving the Delta. NDO values can be estimated from CALSIM II and DSM2 data using a variety of techniques summarized below:

- ❑ Mass balance of system inflows and outflows
    - – CALSIM II Output: NDO = Inflows + Precipitation – Exports – Consumptive Use (Eqn. 5-2)
    - – DSM2 Output: NDO = Inflows – Exports – DICU (Eqn. 5-3)

- ❑ Summation of flows that represent all Delta outflow sources
    - – CALSIM II Output: NDO = D1641 Delta Outflow + Other Outflow Requirements (Eqn. 5-1)
    - – DSM2 Output: NDO = Average Martinez Flow (Eqn. 5-4)
    - – DSM2 Output: NDO = Average Flow Chipps Island + Montezuma Slough (Eqn. 5-5)
    - – DSM2 Output or USGS UVM station data:
      NDO = Average Flow Rio Vista + 3-Mile Slough + Jersey Point + Dutch Slough (Eqn. 5-6)

NDO computations using the above relationships may not result in identical NDO values due to a variety of reasons:

- ❑ CALSIM II and DSM2 do not necessarily use identical representations for all Delta inflows and withdrawals
    - – Inclusion of Marsh Creek inflow in CALSIM but not in DSM2 [max 375 cfs for 2020 Integrated wy1975-1991]
    - – Smoothing of monthly CALSIM II flows for the Sacramento and San Joaquin River to daily values in DSM2 [average difference over 15-years of zero cfs, however monthly differences were up to 135 cfs for 2020 Integrated wy1975-1991]

- ❑ Complex dynamics of unsteady flows in tidal systems
    - – Filling and draining of the Delta during spring-neap cycles
    - – Travel time of transient Delta flows
    - – Ability of data processing technique used to compute NDO parameters to reflect tidal dynamics (monthly average, 24.75 hour running average, Godin filter, etc)
    - – Seasonal pattern of stage at Martinez (typically lower in winter and spring and higher in summer and fall)

5.6 References

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Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

25th Annual Progress Report
October 2004

Chapter 6:
Net Delta Outflow Computations for DSM2 Steady State Simulations

Author: Jamie Anderson

6 Net Delta Outflow Computations for DSM2 Steady State Simulations

6.1 Introduction

Several steady state DSM2 simulations were conducted to investigate impacts of tidal dynamics on Net Delta Outflow (NDO) computations and are documented in this chapter. Three separate steady state DSM2 simulations were conducted to examine NDO computations:

❑ Monthly varying steady state inflows and exports with a constant stage boundary at Martinez

❑ Monthly varying steady state inflows and exports with a repeating 19-year mean tide boundary at Martinez

❑ Steady state (fixed) inflows and exports with an Adjusted Astronomical Tide boundary at Martinez

Descriptions of each study and results are presented in this chapter.

6.2 Time Varying Steady State Inflows and Exports with Constant Stage Boundary at Martinez

A steady state DSM2 simulation with constant stage boundary conditions at Martinez was run to verify that computing NDO by summing flows at the following locations reflects all of the Delta outflow sources (see Chapter 5; Anderson, 2004):

❑ Martinez (DSM2 channel 441)

❑ Chipps Island and Montezuma Slough (DSM2 channels 437, 442, and 511)

❑ Sacramento River at Rio Vista, 3-Mile Slough, San Joaquin River at Jersey Point, and Dutch Slough (DSM2 channels 430, 309, 83, and 274)

The input NDO for the steady state simulation will be computed as a mass balance between the inflows and withdrawals from the system. Previous studies have shown that the four-point solution technique used in DSM2 conserves mass (Nader, 1993). Thus, if the locations above reflect all of the Delta outflow sources, the NDO computed by summing the flows at those locations will be identical to the input NDO.

The simulation was run with steady boundary conditions that varied every two months for Sacramento and San Joaquin River flows and for SWP and CVP exports (Table 6.1). The simulation had a constant stage boundary condition at Martinez and did not include Delta Island Consumptive Use (DICU) or operations of the Delta Cross Channel, Montezuma Salinity Control Gates, or any South Delta barriers. The steady time varying boundary conditions

represent NDO ranging from 7600 cfs to 52600 cfs (approximately 10, 50, 75 and 90th percentile NDO values from the South Delta Improvement Project's 2020 Integrated simulation). Months 1 to 8 of the simulation represent increasing NDO conditions. Months 8 to12 represent dramatic changes in NDO between the highest to the lowest values.

NDO was computed for the three locations (Martinez, Chipps, and Rio Vista/Jersey Point) based on the output from the DSM2 steady state simulation. The transition period between the different boundary conditions was three days. With the exception of this transition period, computed NDO values equaled the input NDO (Table 6.2). Computations for both 7600 cfs (months 1 to 2 and 9 to10) and 52600 cfs (months 7 to 8 and 11 to12) NDO time periods equaled the input NDO indicating that transient flows during the transitions were properly represented in DSM2.

Table 6.1: Boundary Conditions for a Steady State DSM2 Simulation with Constant Martinez Stage.

Month	Inflows (cfs)					Exports (cfs)					DICU (cfs)		Stage (ft)	NDO (cfs)
	Sac	SJR	Cal	Mok/Cos	Yolo	SWP	CVP	CCC	NBA	Vallejo	Nodal DICU	BBID CU	Martinez	Input NDO
1	**8000**	**1000**	50	300	50	**750**	**750**	200	75	25	0	0	1.0	*7600*
2	**8000**	**1000**	50	300	50	**750**	**750**	200	75	25	0	0	1.0	*7600*
3	**15000**	**2000**	50	300	50	**3000**	**3000**	200	75	25	0	0	1.0	*11100*
4	**15000**	**2000**	50	300	50	**3000**	**3000**	200	75	25	0	0	1.0	*11100*
5	**20500**	**5300**	50	300	50	**6300**	**4200**	200	75	25	0	0	1.0	*15400*
6	**20500**	**5300**	50	300	50	**6300**	**4200**	200	75	25	0	0	1.0	*15400*
7	**52500**	**13000**	50	300	50	**8500**	**4500**	200	75	25	0	0	1.0	*52600*
8	**52500**	**13000**	50	300	50	**8500**	**4500**	200	75	25	0	0	1.0	*52600*
9	**8000**	**1000**	50	300	50	**750**	**750**	200	75	25	0	0	1.0	*7600*
10	**8000**	**1000**	50	300	50	**750**	**750**	200	75	25	0	0	1.0	*7600*
11	**52500**	**13000**	50	300	50	**8500**	**4500**	200	75	25	0	0	1.0	*52600*
12	**52500**	**13000**	50	300	50	**8500**	**4500**	200	75	25	0	0	1.0	*52600*

Bold values vary over time.

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Table 6.2: Monthly Average NDO Computations for a DSM2 Steady State Simulation with Time Varying Boundary Conditions and Constant Stage at Martinez.

Location	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
Input NDO	*7,600*	*11,100*	*15,400*	*52,600*
Martinez	7,600	11,100	15,400	52,600
Total NDO at Martinez	*7,600*	*11,100*	*15,400*	*52,600*
Chipps S	7,338	10,717	14,869	50,788
Chipps N	107	156	217	741
Montezuma Slough Upstream	155	226	314	1,070
Total NDO at Chipps Island	*7,600*	*11,100*	*15,400*	*52,600*
Rio Vista	5,076	9,495	12,997	33,892
3-Mile Slough	-160	-880	-1,171	-434
Jersey Point	2,606	2,683	3,862	18,407
Dutch Slough	78	-199	-287	734
Total NDO at Rio Vista/Jersey Point	*7,600*	*11,100*	*15,400*	*52,600*

+ flows are downstream (ebb), - flows are upstream (flood)

6.3 Time Varying Steady State Inflows and Exports with a Repeating 19-Year Mean Tide Boundary at Martinez

Analysis of results from a steady state DSM2 simulation with a constant stage boundary condition at Martinez verified that NDO could be estimated by summing flows at three different locations in the Delta, Martinez, Chipps Island, and Rio Vista/Jersey Point (see section 6.2 for details). In order to investigate impacts of a changing tidal boundary condition on the NDO computations, another steady state DSM2 simulation was run with identical flow and export boundary conditions (Table 6.1) and a repeating 25-hour tidal boundary condition at Martinez. A 25-hour time series of hourly values representing the 19-year mean tide was repeated for the one year simulation period to provide the tidal boundary condition at Martinez (Table 6.3 and Figure 6.1). This tide, more commonly referred to as a design repeating tide, does not take into account spring-neap tidal affects (Nader, 2001). The simulation did not include DICU or operations of the Delta Cross Channel, Montezuma Salinity Control Gates, or any South Delta barriers.

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Table 6.3: 25-Hour 19-Year Mean Tidal Stage Values.

Hour	19-Year Mean Tidal Stage, ft	Hour	19-Year Mean Tidal Stage, ft
1	3.02	13	4.05
2	2.75	14	3.32
3	2.08	15	2.24
4	1.28	16	0.85
5	0.36	17	-0.33
6	-0.01	18	-1.18
7	0.07	19	-1.77
8	0.78	20	-1.80
9	1.87	21	-1.15
10	2.66	22	-0.08
11	3.48	23	1.01
12	4.03	24	1.97
		25	2.70
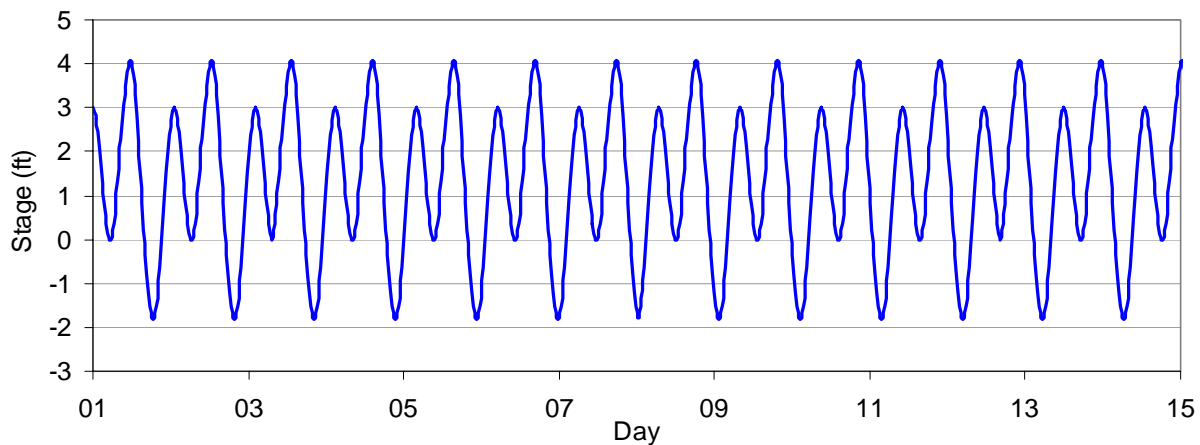
Figure 6.1: Repeating 25-Hour 19-Year Mean Tide.

Monthly NDO was computed for the three NDO locations (Martinez, Chipps, and Rio Vista/Jersey Point) using 15-minute instantaneous DSM2 flow results (Table 6.4). Monthly NDO results are reported for the months in which there was no transition in the boundary flows from the previous month (months 2, 4, 6, and 8 in Table 6.1; Note that results for month 2 and 10 and months 8 and 12 were equivalent). The computed NDO values did not match the input NDO values since the monthly average values were computed based on calendar months. Monthly time periods do not coincide with equal intervals of the tidal cycle, 25 hours in this case, and thus the monthly average computations include partial tidal cycles. Tidal flows at the locations used in the NDO computations can vary dramatically. For the 7600cfs NDO case, Martinez flows vary between 625,000 cfs (ebb) and -525,000 cfs (flood). Thus flow values during a partial tidal cycle can have a dramatic impact on the monthly averages, as illustrated by the comparison of input NDO and calculated NDO in Table 6.4. At Martinez the largest difference between input NDO and computed NDO was nearly 50% for the 7600 cfs NDO conditions. For the NDO

computations at Rio Vista/Jersey Point, the largest difference between input NDO and computed NDO was about 13% for the 7600 cfs NDO conditions.

To improve the NDO estimates, 25-hour running averages were computed from the 15-minute instantaneous DSM2 flow output so that the data averaging reflected the same time period as the tidal cycle, a 25-hour repeating tide in this case. Monthly averages were then computed from the 25-hour running average flow data. Using the monthly average of the 25-hour running average data to compute NDO for the three different locations produced results that were nearly identical to the input NDO for the 7600cfs NDO scenario (maximum difference of 4 cfs), and identical for the other NDO scenarios (11,100 cfs to 52,600 cfs) (Table 6.5). The NDO computations produced identical NDO values to the input NDO because the 25-hour running average represents the entire 25-hour tidal cycle used in the repeating 19-year mean tide. These results indicate the importance using a data processing technique to compute NDO values that reflects the tidal cycle.

Table 6.4: Monthly Average NDO Computations based on 15-Minute Data for a DSM2 Steady State Simulation with Time Varying Boundary Conditions and a 25-Hour Repeating 19-Year Mean Tide at Martinez.

Location	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
Simulation Month	2 and 10	4	6	8 and 12
Input NDO	*7,600*	*11,100*	*15,400*	*52,600*
Martinez	3,815	9,358	15,842	55,761
Total NDO at Martinez	*3,815*	*9,358*	*15,842*	*55,761*
Chipps N	378	433	509	972
Chipps S	5,340	9,551	14,115	52,600
Montezuma Slough Upstream	-101	-28	22	720
Total NDO at Chipps Island	*5,617*	*9,956*	*14,647*	*54,292*
Rio Vista	2,597	6,604	10,538	34,084
3-Mile Slough	-593	-794	-970	785
Jersey Point	4,748	4,895	5,046	18,104
Dutch Slough	-148	-192	-208	448
Total NDO at Rio Vista/Jersey Point	*6,605*	*10,513*	*14,405*	*53,420*

+ flows are downstream (ebb), - flows are upstream (flood)

Table 6.5: Monthly Average NDO Computations based on 25-Hour Running Average Data for a DSM2 Steady State Simulation with Time Varying Boundary Conditions and a 25-Hour Repeating 19-Year Mean Tide at Martinez.

Location	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
Simulation Month	2 and 10	4	6	8 and 12
Input NDO	*7,600*	*11,100*	*15,400*	*52,600*
Martinez	7,604	11,099	15,397	52,599
Total NDO at Martinez	*7,604*	*11,099*	*15,397*	*52,599*
Chipps N	412	456	507	938
Chipps S	7,291	10,671	14,837	50,938
Montezuma Slough Upstream	-104	-27	56	724
Total NDO at Chipps Island	*7,600*	*11,100*	*15,400*	*52,600*
Rio Vista	3,029	6,909	10,615	33,725
3-Mile Slough	-490	-738	-809	699
Jersey Point	5,166	5,095	5,767	17,764
Dutch Slough	-106	-167	-172	412
Total NDO at Rio Vista/Jersey Point	*7,600*	*11,100*	*15,400*	*52,600*

+ flows are downstream (ebb), - flows are upstream (flood)

6.4 Steady State Inflows and Exports with an Adjusted Astronomical Tide Boundary at Martinez

To examine effects of the spring-neap tidal cycle on NDO computations, a steady state DSM2 simulation was run using an Adjusted Astronomical Tide boundary condition at Martinez. Except for the tide boundary, the boundary conditions for the Adjusted Astronomical Tide simulation were identical to the time periods in the previous scenarios corresponding to a NDO of 7600 cfs (Table 6.6). The simulation did not include DICU or operations of the Delta Cross Channel, Montezuma Salinity Control Gates, or any South Delta barriers.

An Adjusted Astronomical Tide is a computed 15-minute varying tidal stage time series that estimates observed tidal stage data. An Adjusted Astronomical Tide is computed by modifying (adjusting) the astronomical tide at a given location to incorporate long-period wave components. For DSM2, an Adjusted Astronomical Tide is computed at Martinez using long-period wave components from observed data at San Francisco. The Adjusted Astronomical Tide represents both the daily tidal cycle and the spring-neap tidal cycle (Figure 6.2) (Ateljevich, 2001).

Table 6.6: Boundary Conditions for Steady State DSM2 Simulation with an Adjusted Astronomical Tide Boundary at Martinez.

Inflows (cfs)					Exports (cfs)					DICU (cfs)		Stage (ft)	NDO (cfs)
Sac	SJR	Cal	Mok/Cos	Yolo	SWP	CVP	CCC	NBA	Vallejo	Nodal DICU	BBID	Martinez	Computed NDO
8000	1000	50	300	50	750	750	200	75	25	0	0	AAT	7600

AAT=Adjusted Astronomical Tide
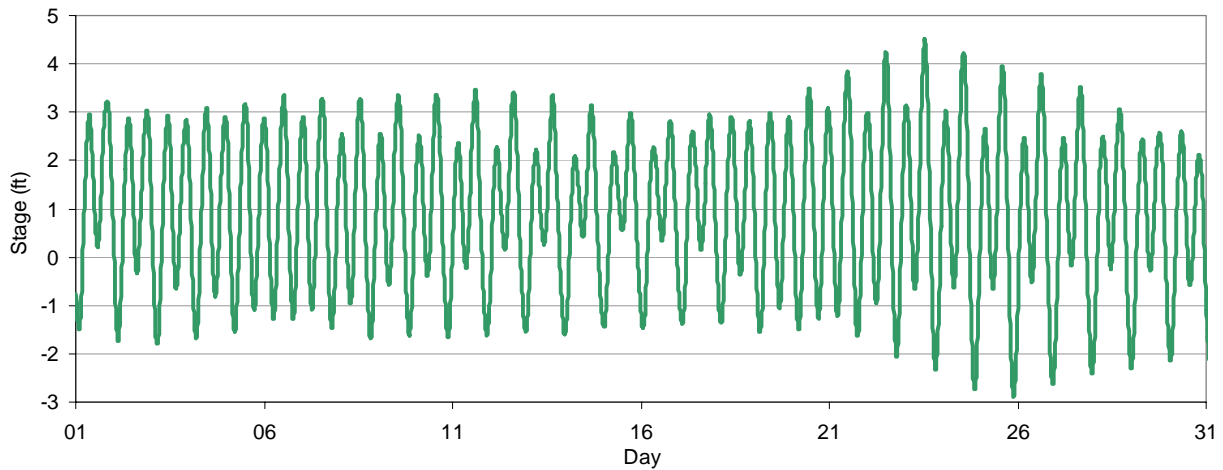
Figure 6.2: Adjusted Astronomical Tide for First Month of Steady State Simulation.

Simulation results were analyzed for a one year time period with the Martinez Adjusted Astronomical Tide input for water year (wy) 1977. Note that the tidal input is reflective of wy1977, however the inflows and exports were steady values representative of a 7600 cfs NDO (Table 6.6). In addition to the approximately two week spring-neap tidal cycle, the Adjusted Astronomical Tide represents seasonal patterns in tidal stage. The monthly average stage at Martinez for the one year time period was 0.71 ft. However, monthly averages ranged from a maximum of 0.97 ft (Sep.) to a minimum of 0.27 ft (Mar. and Apr.) (Table 6.7). The monthly average stage is affected by the spring-neap tidal cycle, the amount of fresh water inflow to the system, and atmospheric pressure conditions. Higher stages are correlated to lower fresh water inflows, and thus more intrusion of ocean water. Monthly average stage values in Table 6.7 indicate a typical seasonal pattern of stage at Martinez with lower stages in the winter and spring and higher stages in the summer and fall.

Table 6.7: Average Martinez Stage (ft) for Steady State Simulation with an Adjusted Astronomical Tide Boundary at Martinez

Mon/WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	*AVG*
AAT 1977	0.91	0.86	0.95	0.83	0.58	***0.27***	***0.27***	0.45	0.71	0.77	0.92	**0.97**	*0.71*

AAT=Adjusted Astronomical Tide, Bold indicates maximum and minimum values

NDO computations for the 25-hour repeating tide scenario discussed in the previous section indicated the importance of using a data processing technique that reflects the tidal cycle. The Adjusted Astronomical Tide occurs on a lunar calendar not on a Gregorian calendar. A tidal day (or lunar day) is 24 hour and 50 minutes long, and a tidal month (or lunar month) is 29.53 days long (USDC, 2000). A single spring-neap tidal cycle occurs over half of a lunar month (14.77 days).

If calendar monthly average flows are used to compute NDO using data from an Adjusted Astronomical Tide simulation, the length of the month does not correspond to exactly two spring-neap tidal cycles. In certain months, there may be more spring flows (highest tidal amplitude), and in others there may be more neap flows (lowest tidal amplitude). For the steady state simulation, monthly average flow values were used to compute NDO at three locations (Figure 6.3 and Table 6.8). For the 7,600 cfs NDO steady state simulation, the largest positive difference between computed and input NDO (computed NDO > input NDO) occurred during July 1977, a month that had more spring flows than neap flows. Similarly, the largest negative difference between computed and input NDO (computed NDO < input NDO) occurred during April 1977, a month that had more neap flows than spring flows.

For the monthly averaged data NDO computations, the NDO values were typically closer to the input NDO as the NDO computation sites move further upstream from Martinez, i.e. the computed NDO using the furthest upstream sites (Rio Vista/Jersey Point) was closer to the input NDO than NDO computed from sites further downstream (Chipps Island and Martinez) (Figure 6.3 and Table 6.8). For Martinez, the average difference in monthly NDO was 199 cfs with differences ranging from approximately -1420 cfs to 1817 cfs. For Chipps Island, the average difference in monthly NDO was 151 cfs with differences ranging from -916 cfs to 1003 cfs. For Rio Vista/ Jersey Point, the average difference in monthly NDO was 105 cfs with differences ranging from -606 cfs to 513 cfs. The NDO estimates typically followed a seasonal pattern with NDO estimates greater than the input NDO when average Martinez stage was higher and with NDO estimates lower than the input NDO when average Martinez stage was lower (Figure 6.3).

Typically NDO computations using Adjusted Astronomical Tide data can be improved by using a data processing technique that reflects the tidal cycle. Since DSM2 uses 15-minute computational time steps, simulated data were processed using a 24.75 hour running average, the closest 15-minute interval to a 24 hour 50 minute lunar day. Monthly NDO was computed at the three locations (Martinez, Chipps Island, and Rio Vista/Jersey Point) using monthly averages of 24.75 hour running average flow data (Figure 6.4 and Table 6.9). For the one year of data analyzed, the overall average difference between computed NDO and input NDO was lower for the 24.75 hour running average computation than for the monthly average computation (51 cfs vs 199 cfs for Martinez NDO, 32 cfs vs 151 cfs for Chipps NDO, and 22 cfs vs 105 cfs for Rio Vista/Jersey Point NDO). However for individual months, there is not a consistent trend as to

which estimation technique provides the closest NDO estimate to the input NDO, and neither approximation matches the input NDO exactly. For the 24.75 hour running average NDO computations, the ranges in differences in NDO for the computed values compared to the input NDO were smaller than for the NDO computed from monthly averages (-704 to1093 cfs vs -1420 to 1817 cfs for Martinez, -402 to 688 cfs vs -916 to 1003 cfs for Chipps, and -337 to 478 cfs vs -606 to 513 cfs for Rio Vista/Jersey Point).

Regardless of data processing technique used (monthly average and 24.75 hour running average), the computed NDO based on DSM2 output was closer to the input NDO at the site furthest upstream (Rio Vista/Jersey Point). This site would be least impacted by complex tidal dynamics. Also for both data processing techniques, the largest positive difference between computed and input NDO (computed NDO > input NDO) occurred during a month that had more spring flows than neap flows (July), and the largest negative difference between computed and input NDO (computed NDO < input NDO) occurred during a month that had more neap flows than spring flows (April).

Computing NDO based on DSM2 simulation data for Adjusted Astronomical Tide simulations does not produce NDO values that are identical to the input NDO. The input NDO computation does not incorporate complex tidal dynamics such as:

- ❏ Filling and draining of the Delta during spring-neap tidal cycles
- ❏ Seasonal variations in stage at Martinez
- ❏ Transient flows

Typically NDO estimates can be improved by using data processing techniques that account for the length of a tidal cycle such as a 24.75 hour running average or a Godin filter (Godin, 1972).

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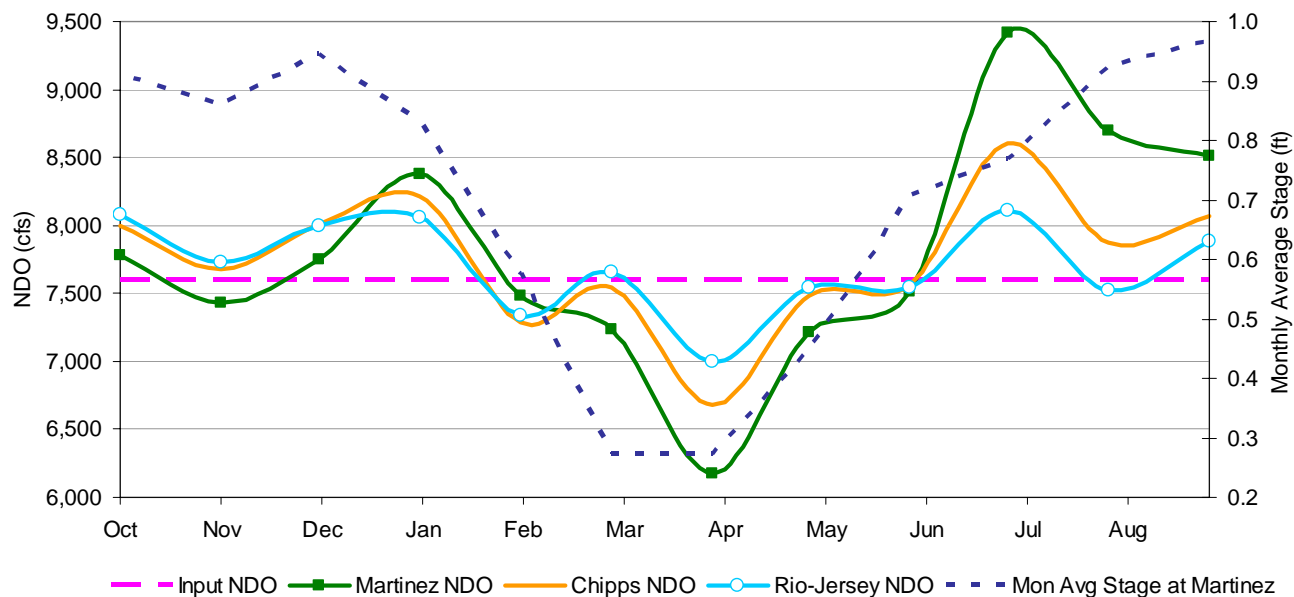
Figure 6.3: Monthly NDO Computed from Monthly Averaged 15-Minute Data for a Steady State Simulation with an Adjusted Astronomical Tide at Martinez.
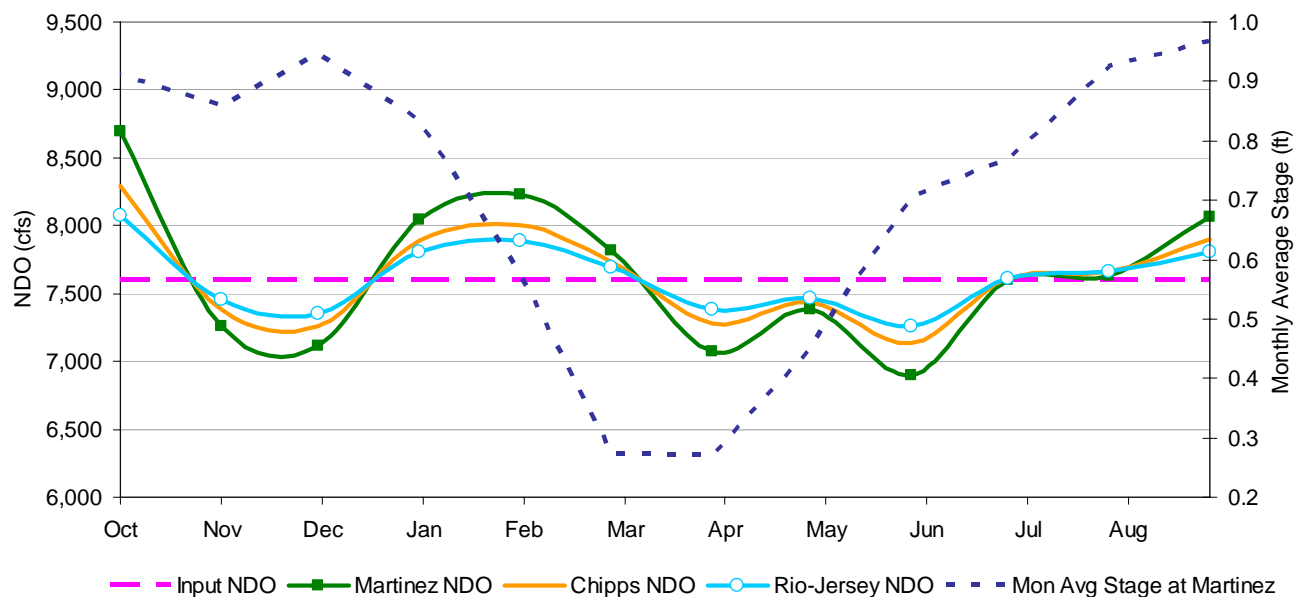
Figure 6.4: Monthly NDO Computed from Monthly Averages of 24.75 Hour Running Average Data for a Steady State Simulation with an Adjusted Astronomical Tide at Martinez.

Table 6.8: Monthly NDO Computed from Monthly Averaged 15-Minute Data for a Steady State Simulation with an Adjusted Astronomical Tide at Martinez.

Tide Date	Inflow NDO	Martinez		Chipps Island		Rio Vista/Jersey Point	
		Computed NDO	NDO Difference	Computed NDO	NDO Difference	Computed NDO	NDO Difference
Oct-76	7,600	7,781	181	7,995	395	8,077	477
Nov-76	7,600	7,428	-172	7,674	74	7,724	124
Dec-76	7,600	7,745	145	8,008	408	7,994	394
Jan-77	7,600	8,374	774	8,211	611	8,055	455
Feb-77	7,600	7,487	-113	7,291	-309	7,339	-261
Mar-77	7,600	7,237	-363	7,548	-52	7,661	61
Apr-77	7,600	6,180	-1,420	6,684	-916	6,994	-606
May-77	7,600	7,214	-386	7,484	-116	7,544	-56
Jun-77	7,600	7,510	-90	7,568	-32	7,546	-54
Jul-77	7,600	9,417	1,817	8,603	1,003	8,113	513
Aug-77	7,600	8,697	1,097	7,873	273	7,529	-71
Sep-77	7,600	8,516	916	8,073	473	7,886	286
Max	*7,600*	*9,417*	*1,817*	*8,603*	*1,003*	*8,113*	*513*
Avg	*7,600*	*7,799*	*199*	*7,751*	*151*	*7,705*	*105*
Min	*7,600*	*6,180*	*-1,420*	*6,684*	*-916*	*6,994*	*-606*

Note: NDO differences are computed NDO minus Inflow NDO.

Table 6.9: Monthly NDO Computed from Monthly Averages of 24.75 Hour Running Average Data for a Steady State Simulation with an Adjusted Astronomical Tide at Martinez.

Tide Date	Inflow NDO	Martinez		Chipps Island		Rio Vista/Jersey Point	
		Computed NDO	NDO Difference	Computed NDO	NDO Difference	Computed NDO	NDO Difference
Oct-76	7,600	8,693	1,093	8,288	688	8,078	478
Nov-76	7,600	7,260	-340	7,388	-212	7,455	-145
Dec-76	7,600	7,118	-482	7,258	-342	7,351	-249
Jan-77	7,600	8,046	446	7,887	287	7,803	203
Feb-77	7,600	8,229	629	8,000	400	7,892	292
Mar-77	7,600	7,820	220	7,731	131	7,694	94
Apr-77	7,600	7,076	-524	7,276	-324	7,384	-216
May-77	7,600	7,386	-214	7,436	-164	7,466	-134
Jun-77	7,600	6,896	-704	7,138	-462	7,263	-337
Jul-77	7,600	7,598	-2	7,612	12	7,611	11
Aug-77	7,600	7,634	34	7,663	63	7,658	58
Sep-77	7,600	8,061	461	7,904	304	7,809	209
Max	*7,600*	*8,693*	*1,093*	*8,288*	*688*	*8,078*	*478*
Avg	*7,600*	*7,651*	*51*	*7,632*	*32*	*7,622*	*22*
Min	*7,600*	*6,896*	*-704*	*7,138*	*-462*	*7,263*	*-337*

Note: NDO differences are computed NDO minus Inflow NDO.

6.5 Summary

Monthly varying steady state DSM2 simulations were run with a variety of tidal boundary conditions at Martinez (constant stage, 25-hour repeating 19-year mean tide, and Adjusted Astronomical Tide) to investigate effects of tidal dynamics on Net Delta Outflow computations. Conclusions from the studies are summarized below.

Time Varying Steady State Simulation with Constant Stage Boundary at Martinez

❑ The following three methods of computing NDO reflect all sources of Delta outflow:

– NDO = Average Martinez Flow

– NDO = Average Flow Chipps Island + Montezuma Slough

– NDO = Average Flow Rio Vista + 3-Mile Slough + Jersey Point + Dutch Slough

❑ Verifying the above NDO equations with a constant stage steady state DSM2 simulation also demonstrated that DSM2 conserves mass (see also Nader, 1993)

❑ DSM2 accurately represents large transitions in boundary flows

Time Varying Steady State Simulation with a 25-Hour Repeating 19-Year Mean Tide Boundary at Martinez

❑ Data used in NDO computations needs to be processed to reflect the tidal cycle in order to calculate the correct NDO (e.g. 25-hour running average)

❑ For a 25-hour repeating 19-year mean tide, the exact length of the tidal cycle is known, therefore NDO computed using average flows at three locations (Martinez, Chipps Island, and Rio Vista/Jersey Point) will be equivalent to the DSM2 input NDO

❑ After a several day transition period when boundary flows changed, the NDO computed using average flows at three locations (Martinez, Chipps Island, and Rio Vista/Jersey Point) was equivalent to the DSM2 input NDO, even for very large changes in NDO (7,600 cfs to 52,600 cfs)

Steady State Simulation with an Adjusted Astronomical Tide Boundary at Martinez

❑ When spring-neap tidal effects are incorporated into a DSM2 simulation, NDO computations at different locations may not result in values identical to the input NDO or to each other due to a variety of reasons related to complex dynamics of unsteady flows in tidal systems:

– Filling and draining of the Delta during spring-neap cycles

– Travel time of transient Delta flows

– Ability of data processing technique used to compute NDO parameters to reflect tidal dynamics (monthly average, 24.75 hour running average, Godin filter, etc)

– Seasonal pattern of stage at Martinez (typically lower in winter and spring and higher in summer and fall)

6.6 References

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Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 7:
Extensions and Improvements to DSM2

Author: Ralph Finch, Eli Ateljevich, Edward Diamond, and Tawnly Pranger

7 Extensions and Improvements to DSM2

7.1 Introduction

The DSM2 database extension project was described in the 2002 Annual Report (Ateljevich and Pranger, 2002). Since then, the project has increased in scope to include other major changes. This chapter reviews the database portion of the project, describes the other improvements, and provides a status report of the project. The new version of DSM2, referred to as DSM2-DB, includes features in addition to the database.

7.2 Major Extensions in DSM2-DB

The conversion of DSM2-DB to read fixed (non-time-varying) data from a **relational database** instead of from text files continues to be the main extension of DSM2-DB. Reasons for embarking on the Database component include:

❑ Providing better guarantee that different studies using the same Delta design elements will use identical parameters,

❑ Allowing easier implementation of a Graphical User Interface (GUI),

❑ Providing a mechanism for developing and testing REALM (Ateljevich and Finch, 2004), and

❑ Shifting to industry-standard methods and software wherever feasible, which reduces development costs and offers a much higher quality end product.

The Microsoft Access database was initially chosen to store DSM2 input data because of its low cost and ubiquity. Some initial problems with multi-user access and replication led to the decision to move to a more robust multi-user database system, with Access being retained as the public, single-user database. Firebird (the open-source version of Borland's Interbase) was chosen as the Section database until an Informix server is available later in the year. A Visual Basic script was used to move both the data structure and contents from MS Access. Another script will be constructed to move the final data structure and contents from Informix to Access (round-trip capability) to facilitate data sharing.

Firebird has worked out well as a development platform for a multi-user database. Its built-in stored procedure language provides an easy implementation of data integrity and check constraints. The security system allows individual modelers to create their own related data layers that are secure from modification by other database users. This security system has been comprehensively tested to insure that it works as intended.

7.2.1 Graphical Users Interface (GUI)

A closely related extension is the development of a **companion GUI** to the Database. This is also described by Ateljevich and Pranger (2002) and the appearance has not changed greatly from that report. In addition to facilitating manipulation of data in the Database, the GUI enables easier review of changes from an initial study.

For instance, Figure 7.1 shows the *Gate Time Series* input panel (right frame of the image in Figure 7.1) for an experimental permanent barrier planning run. To simplify the test run, the Montezuma Slough Salinity Control Structure was not supported by removing the time series input for its gate operation from the input in the *Planning Operation Gates* layer (lower left *Input Layers* panel in Figure 7.1).

The same *Gate Time Series* panel shows that, for the Old River at Head barrier, the operation of the flashboards and radial gates have been over-ridden from a timed operation from a DSS file to a fixed, always-open state, as evidenced by the light-gray text of the superseded condition.
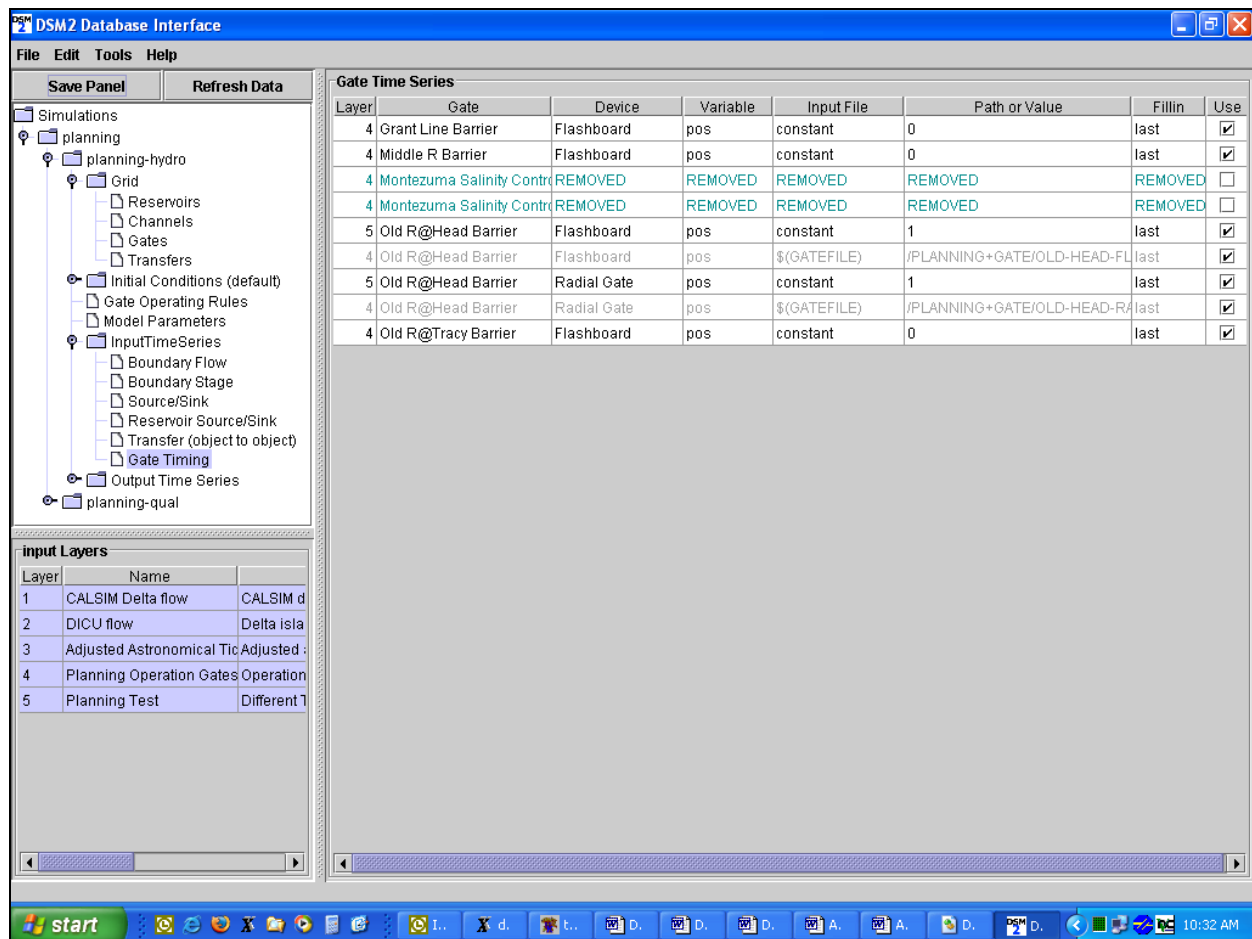
Figure 7.1: Gate Timing Panel of DSM2-DB GUI Illustrating Entries Removed and Changed with Higher Layers.

GUIs are helpful for making relatively small additions or changes to input, but are inconvenient for manipulating large amounts of data, or for repetitive tasks. Scripts have been developed that access the database, interact with its security system, and add data in bulk. The prototype application was a script that stores channel cross-section data generated by the Cross-Section Development Program (Tom, 1998).

7.2.2 Gates

Other major extensions in DSM2-DB are more flexible **gate specifications** and **reformulation of internal gate calculations**. In the current version of DSM2, gates have only one basic weir and/or pipe configuration (with multiple numbers of identical weirs and pipes). Gates can be located at channels or reservoirs, but the internal representation of channel and reservoir gates are different and reservoir gates such as the Clifton Court Forebay gates have much less functionality than channel gates.

The following features have been applied to gates:

❑ Gates now are collections of *devices* such as pipes and weirs.

❑ Devices contain the physical dimensions and parameters of what has until now been called gates.

❑ An arbitrary number of devices can be added to a single gate and operated independently. Physical description and properties (width, flow parameter) are applied to each device in its device description, not to the gate as a whole as in previous versions of DSM2.

Figure 7.2 illustrates a *Gate Input* panel. Higher numbered layers override specifications in lower layers. The pipe and weir devices contained in a gate are shown in the bottom half of the right panel. In this example, the Boat Lock for the Head of Old River barrier is displayed.

These modifications will satisfy a number of user requests that have emerged over the last two years. For instance, the five gates to Clifton Court Forebay can now be operated independently. The radial gates, flashboards, and boat lock of the Montezuma Salinity Control Structure can likewise be configured and operated independently. Finally, the option to treat duplicate pipe and weir devices as a single group is still available to preserve simplified gate treatment due to lack of detailed data.

Gate flow calculations have been reformulated and transformed in a manner that is mathematically equivalent and more amenable. This should improve gate flow accuracy and allow true gates to be connected to reservoirs. The older and simpler connection to channels has been retained for reservoirs with no actual gates, but the new method is used for the Clifton Court Forebay gates.
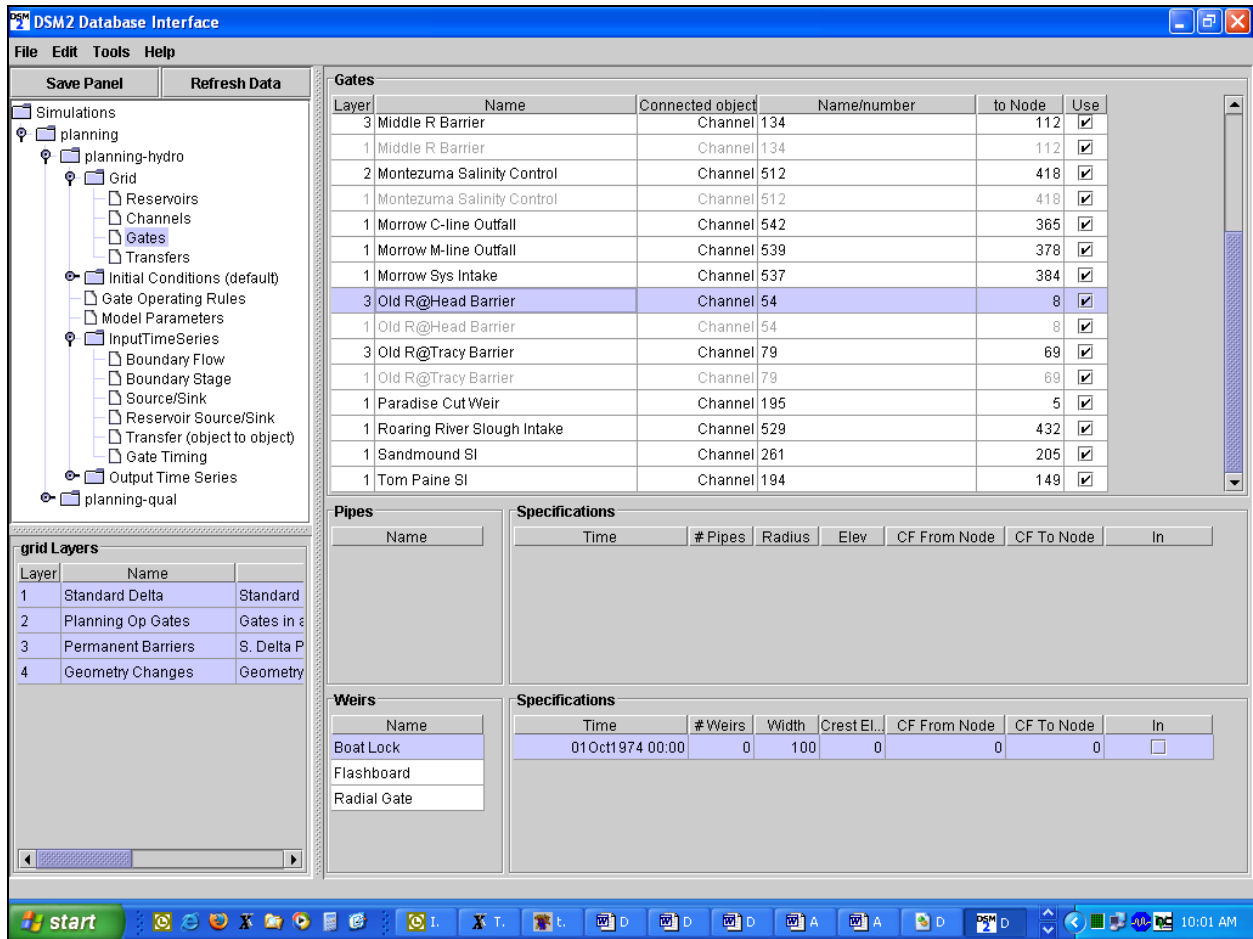
Figure 7.2: Gate Input Panel Illustrating Gate Devices and Layers.

7.2.3 Expressions and Operating Rules

Another major addition to DSM2-DB are **Operating Rules**: a *trigger* and subsequent *action*. Operating rules allow the user to model features such as gate operations and pumping changes which in the field would be managed adaptively based on conditions in the Delta. An example is to close a radial gate in response to low stage in Middle River. This is not possible in the current version of DSM2 where adaptive decisions are simulated through an iterative process.

Operating rules for gates have been available in test versions of DSM2-DB for several months, and have been applied to trial planning and historical simulations. Early versions of operating rules allowed the user to adjust the operating coefficient of a gate based on simple observations of the state of the model, such as a single flow or stage value. For the Middle River barrier, for example, it is possible to trigger the opening of a radial gate when stage in a reference channel dips below a threshold value. The trigger can optionally include a short-term anticipation (by extrapolating the current trend in the model forward in time). In DSM2-DB, triggers can only be associated with hydrodynamic parameters, such as stage, stage difference between locations or on each side of a gate, flow, or channel velocity, at user-specified locations. A trigger can also be empty, which means it is applied at the start of a run and continues indefinitely.

7-4

Recently, operating rules have been redesigned and augmented in response to feedback from trial applications. In order to increase the flexibility and expressiveness of the rules, the operating rules utilize both model information and exogenous input such as time series and information about the season. These inputs can also be combined in simple mathematical or logical expressions, examples of which are given below. The operating rule actions can manipulate boundary flows and pumping as well as gates.

The operating rules require an interface that neither limits nor overly complicates their use. DSM2-DB uses a simple interpreted language to write the rules since this is the standard for user-written rules (e.g. SQL for databases or WRESTL for CALSIM), and menu-driven control within a GUI is not flexible enough. Operating rules combine *trigger* and *action* directives, each of which is an expression based on observed model states, seasonal information and exogenous time series input, as well as other triggers and actions.

Actions are responses the model executes when its corresponding *trigger* fires. In DSM2-DB, the actions involve either gate devices or source/sink flow terms (often pumps or drains). For devices, the operating flow coefficient can be changed, as well as the maximum flow allowed through the gate device. For sources and sinks, flow may be specified by either a constant value or a time-series of values.

Expression Examples

An example of a simple numerical expression based on current DSM2-DB flow looks like this:

```
ebb := flow(channel 132, dist 1000) > 0.01
```

This example samples the current time step model flow 1,000 ft downstream of the upstream node in channel 132 and checks whether it is greater than 0.01 cfs. The expression assigns the answer the name *ebb*, so it can be reused. Note that *ebb* is a logical expression which evaluates to *true* or *false* depending on the model time step. Logical variables usually appear in triggers rather than actions.

Besides logical expressions, numeric expressions involving simple math operators can also be defined. For instance:

```
ebbmagnitude := exp(flow(channel 132, dist 1000))
```

is an expression that evaluates flow, applies the exponential function to it and then assigns it to the variable name *ebbmagnitude*.

Model time can also be used in expressions. The following expression describes the VAMP season for San Joaquin river management:

```
vamp := (month == Apr) or (month == May)
```

The definition could also include the date, day of the month, or time of day.

Finally, the following example combines a model state (stage/water surface) observation, an external time series (called tide_level) and simple arithmetic. The expression might be used with a slowly fluctuating tide or sea level datum to provide an idea of critical stage in the South Delta compared to ambient tide conditions.

```
critical_stage := stage(channel 132,
                        dist 1000)<(tide_level-1.0)
```

Operating Rule Examples

It is now straightforward to use expressions in operating rules. The following example is based on expressions that were developed above. **Bold face** words are part of the GUI; `courier type` is user input.

Name: `middle_vamp_ebb`
Expressions:
```
ebb := flow(channel 132, dist 1000) > 0.01
vamp := (month == Apr) or (month == May)
```
Trigger: `vamp and ebb`
Action: `set( weir-op, gate: Middle River Barrier,`
`         weir: Radial Gate) to new_time_series`

The *middle_vamp_ebb* operating rule lies dormant until the first time step when *vamp and ebb* (a compound expression based on the expressions **vamp** and **ebb**) becomes true. At that point the action will be taken and the weir operating coefficient will start to operate according to the values in the DSS time series *new_time_series.*

Anticipation and ramping can be added to numerical expressions in triggers and actions respectively. For instance, an anticipating version of *middle_vamp_ebb* might use the definition for ebb:

```
ebb := predict(flow(channel 132, dist 1000), 45min) > 0.01
```

This example assigns a logical expression *true* or *false* to *ebb* based on the whether the flow 1,000 ft downstream of the upstream node in channel 132 that is predicted 45 minutes from the current time step is greater than 0.01 cfs.

Similarly, the user may wish to gradually introduce the action. This is done using the *ramp* directive, which gradually and linearly implements an action:

```
set( weir-op, gate: Middle River Barrier,
     weir: Radial Gate) to new_time_series ramp 60min
```

Often, an operating rule is paired with a complimentary rule that will reverse its action. For instance, to complement the above rule for ebb flow the following operating rule for flood flow might be added:

Name: `middle_vamp_flood`
Expressions:
```
    flood := flow(channel 132, dist 1000) < -0.01
    vamp := (month == Apr) or (month == May)
```
Trigger: `vamp and flood`
Action: `set( weir-op, gate: Middle River Barrier,`
`            weir: Radial Gate) to old_time_series`

This rule effectively undoes the ebb action. This example underscores a necessary but somewhat unintuitive point about triggers: they are one-time and unidirectional. A rule whose trigger is *vamp and ebb* will activate when this expression changes from false to true but will not deactivate or even notice if *vamp and ebb* subsequently becomes false again. If the complementary behavior is desired, this intent must be specified in a second rule. Often the complementary rule is subtly different from the exact negation of the original; for instance, the trigger `vamp and flood` is not the same as `not(vamp and ebb)`. An important example of this in Delta operations is the Montezuma Salinity Control Structure, when the flood and ebb triggers are not even based on the same variable (the gate is opened based on a head difference, closed based on velocity).

The *middle_vamp_ebb* example combines *vamp,* which is the seasonal applicability of the rule with *ebb*, which is a tidal phenomenon. There are also meaningful operating rules that do not need a trigger at all. For instance, the user might want to operate SWP and CVP pumping based on a time series but bound it by some fraction of Sacramento inflow. The trigger in this case always applies, which is the default in the GUI if you leave the trigger blank. The rule will then read:

Trigger:
Action: `set swp = max(swp_time_series, outflow_fraction)`

7.2.4 Data Format

The last major change to DSM2-DB is the use of **HDF5 (Hierarchical Data Format**, http://hdf.ncsa.uiuc.edu/HDF5/) for hydrodynamic output for QUAL and the PTM.

HDF5 is a general purpose, open source library and file format designed for storing scientific data. It was designed for high performance, data intensive applications and includes compression and support for parallel systems.

The advantages in using HDF5 include generalization, flexibility, and support for large and complex datasets. It can be run on a wide variety of computing systems, ranging from desktop PCs to parallel supercomputing systems.

These aspects of HDF5 provide substantial improvements over the existing tidefile which must be written to and read from in sequence. This requires the file (currently 4 GB in size for a 16-year planning study) to be read beginning to end multiple times. In contrast, data within an HDF5 file can be randomly accessed, allowing for much more efficient retrieval and for very flexible subsets of the entire data sequence to be quickly retrieved. This flexible access allows for a more thoughtful design of how data is stored. The sequential format prevents multiple processes from accessing the same tidefile simultaneously which is not a limitation of HDF5.

Because it supports compression, there is an additional space savings using HDF5. With the use of compression, the size of the existing tidefile is reduced from 4 GB to 2.5 GB. This may enable DSM2-DB to store more data within the file and allow for the use of a single file with the Condor parallel application of the model (see section 7.2.5 for more information about Condor).

As of the date of this report, DSM2-DB is capable of writing to and reading from an HDF5 file. The current file contains most of the data stored in the existing tidefile structure (the exception being an object-to-object transfer).

7.2.5 Parallel Processing

HYDRO runs 50% or slower than QUAL, and thus has been the bottleneck in producing studies. The **Condor distributed computing system** (http://www.cs.wisc.edu/condor/) was implemented on the Delta Modeling Section's local area networked computers. Using Condor's Directed Acyclic Graph Manager (DAGMan) a single HYDRO run can be split into five simultaneous runs (one warm-up year and four production years) on five computers on the LAN. When each run finishes, its output is copied back to the submitting computer. QUAL is started when all runs are finished, and the separate HYDRO outputs are combined into a single DSS file (Figure 7.3). This allows a joint HYDRO and QUAL run to be finished in slightly less than 8 hours using a 3 GHz processor, and should allow reasonable running times for longer runs (e.g. 73-year run on full CALSIM results).

DSM2 Run Using Condor and DAGMan
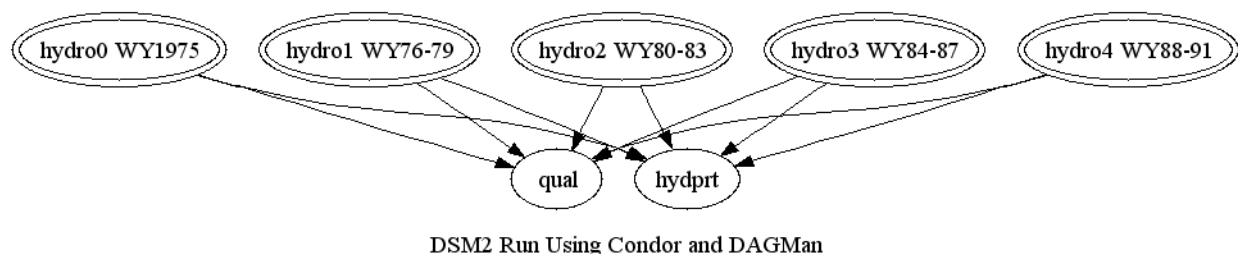
Figure 7.3: Parallelized HYDRO Runs.

7.3 Status & Future Directions

As of April 2004 DSM2-DB HYDRO and QUAL are both running. However, three types of basic runs need to be completed before this version of DSM2 can be placed into production:

❑ Historic, to compare to previous validation,

❑ Planning with South Delta agricultural temporary barriers, and

❑ Planning with permanent South Delta agricultural barriers operated during run.

Each run offers different challenges.

Because better gate descriptions are now available, old gate descriptions may not be adequate. The gate calculations themselves have been changed and thus a small-scale validation of the new gate configurations is needed to confirm that the model results are basically the same as before.

The timing of temporary barriers can be determined before the run starts from San Joaquin River boundary flows. This is being done now with an Excel worksheet. For DSM2-DB the logic behind temporary barrier operation will be converted to a Vscript program which will generate the needed timing and write to a DSS file.

(http://modeling.water.ca.gov/delta/models/dsm2/tools/vista/vscript/intro.html)

Finally, a planning run with permanent barriers is needed which can serve as a basis for other planning run variations. The precise permanent barrier operation is still being determined by other staff members for the South Delta Barriers Project.

7.4 References

Ateljevich, E. and T. Pranger. (2002). "Chapter 13: DSM2 Input Database and Data Management System." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Office of State Water Project Planning. Sacramento, CA.

Ateljevich, E. and R. Finch. (2004). "Chapter 2: REALM Update." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 25th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Bay-Delta Office. Sacramento, CA.

Tom, B. (1998). "Chapter 6: Cross-Section Development Program." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 19th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Office of State Water Project Planning. Sacramento, CA.

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

25th Annual Progress Report
October 2004

Chapter 8:
Real-Time Data and Forecasting Proof of Concept and Development

Author: Michael Mierzwa and Bob Suits

8 Real-Time Data and Forecasting Proof of Concept and Development

8.1 Introduction

Part of the Department's Municipal Water Quality Investigations' (MWQI) mission statement is to monitor and protect the drinking water quality of deliveries to urban State Water Contractors by assisting participating agencies in planning for and achieving future water quality objectives (Breuer, 2002). MWQI's monitoring plan includes the Real-Time Data and Forecasting (RTDF) project whose goals include giving water contractors and stakeholders operational flexibility by predicting water quality in both the Delta and California Aqueduct, and increasing water planners' and decision makers' Delta and California Aqueduct knowledge base.
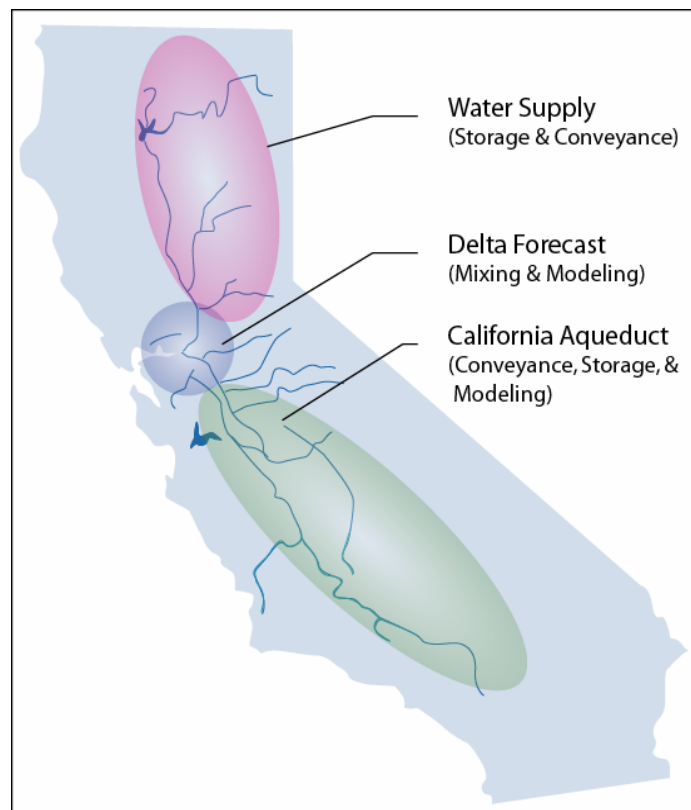
Figure 8.1: Physical Scope of Real-Time Data and Forecasting Project.

The physical scope of RTDF modeling needs to include the entire State Water Project (SWP) system (see Figure 8.1). The SWP can be divided into three principal regions: the northern storage and conveyance facilities, the Sacramento-San Joaquin Delta, and the California Aqueduct system which, in addition to providing additional storage, ultimately delivers the majority of the project water to the water contractors and stakeholders. Each of these regions

presents different forecasting challenges, but a RTDF modeling system requires coupling the individual models used to forecast water supply, demand, and quality in each of these three regions. This chapter addresses the ability of existing tools like DSM2 to forecast SWP drinking water quality (through the proof of concept) and the future development needed to meet the goals of MWQI's RTDF project.

8.2 Background of MWQI and Forecasting

The Department's Division of Environmental Service's Office of Water Quality (OWQ) is responsible for investigating and disseminating water quality data associated with the operation of the State Water Project. Created in July 2002, the OWQ includes water quality programs from the Department's former Environmental Services Office and Division of Planning and Local Assistance and shares an organizational affiliation with the Division of Operation and Maintenance's Office of Water Quality (now known as the State Water Project Water Quality Program Branch). OWQ's Municipal Water Quality Investigations (MWQI) program is directly overseen by a steering committee of the State Water Contractors who receive State Water Project water directly for municipal use (MWQI, 2004). The MWQI steering committee includes members from Urban State Water Contractors, California Urban Water Agencies, Contra Costa Water District, California Department of Health Services, State Water Resources Control Board, and U.S. Environmental Protection Agency

According to the 2002-2004 MWQI Work Plan, one of the main objectives of MWQI is "to acquire, store, assess, and transfer water quality data to the stakeholders and the public" (Breuer, 2002). With this goal in mind, a Real-Time Data and Forecasting (RTDF) steering committee was formed with representatives from the water agencies that take drinking water from the Delta, Operations and Maintenance Division (O&M), Bay-Delta Office Modeling Support Branch, and MWQI. The committee has as its primary responsibilities monitoring, forecasting, and data dissemination.

Monitoring networks provide the real-time historical data that is used as the initial conditions for any forecast. Though current O&M DSM2 forecasts are limited to simulating Delta flow, stage, and electrical conductivity (EC), a major component of the RTDF monitoring activities is to identify the monitoring needs necessary to better understand the entire SWP system. This includes extending the current monitoring network to collect data of other water quality constituents, such as total dissolved solids (TDS), bromide, and organic carbon that can be easily integrated into current water quality forecasts.

The forecasting work of the RTDF is divided into two main tasks: continuing existing forecasts and improving the current forecasting tools. At least once a week O&M forecasts the short-term EC and South Delta water levels using DSM2 (see section 8.3). The development work involved in extending these forecasts to include the entire SWP system, simulating additional water quality constituents, and addressing source water questions (via fingerprinting) is described below (sections 8.5 and 8.6).

8.3   History of Forecasting with DSM2

DSM2 has been used as a Delta hydrodynamic and water quality forecasting tool by the Department of Water Resources for several years. O&M's Operations Compliance and Studies Section has been using the existing DSM2 forecasting methodology (Mierzwa, 2001) to produce one or more forecasts of Delta conditions each week. The hydrodynamic and water quality results of these DSM2 forecasts are used by DWR operators to make adjustments to real-time State Water Project and Central Valley Project operations in order to meet Delta flow and water quality standards. An example of a DWR O&M water quality forecast is shown in Figure 8.2.
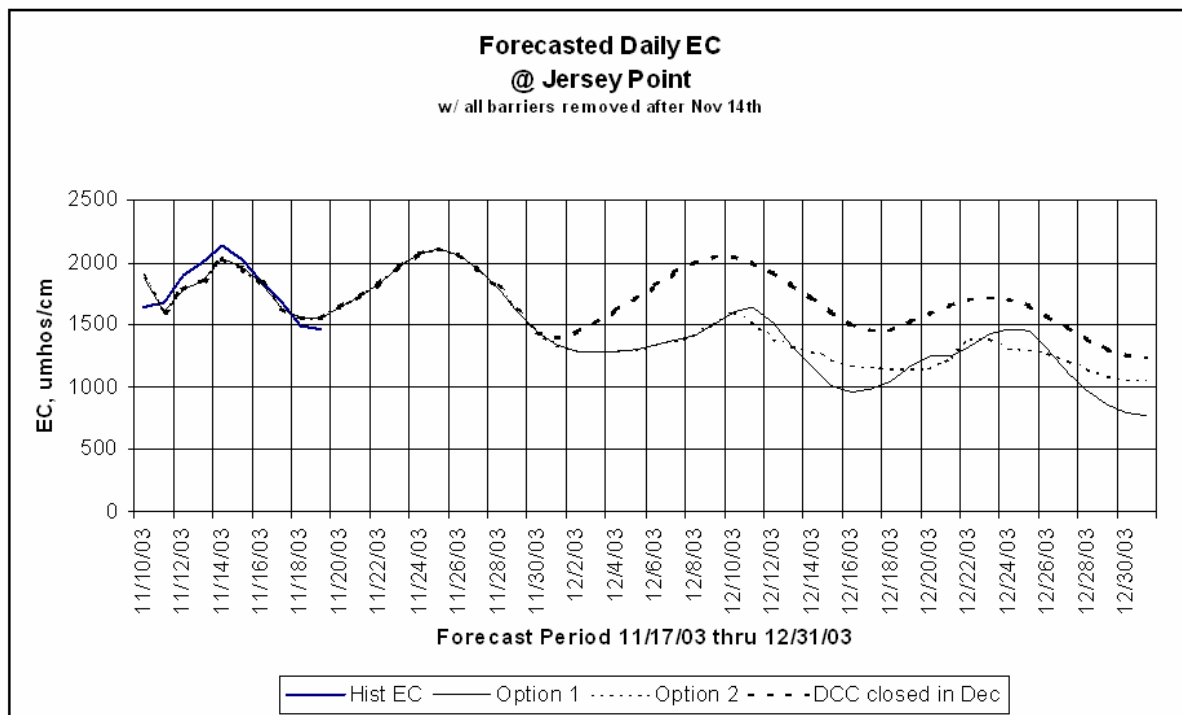
Figure 8.2: Example of Forecasted Water Quality Using DSM2.
(taken from Sun, 2004)

DWR's Bay-Delta Office Temporary Barriers and Lower San Joaquin Section uses the weekly O&M DSM2 forecasts to report both the current and anticipated South Delta water levels. An example of one of these real-time water level forecasts near the Grant Line Canal temporary barrier site is shown below in Figure 8.3. These reports are emailed to any public party with an interest in South Delta water levels and are archived at:

http://sdelta.water.ca.gov/web_pg/tempbar/weekly.html

Forecasted Low-Low Tide Stage
Doughty Cut above GLC Barrier
Note: 2 AG barriers tidally operated, GLC partial, HORB 3 culverts open
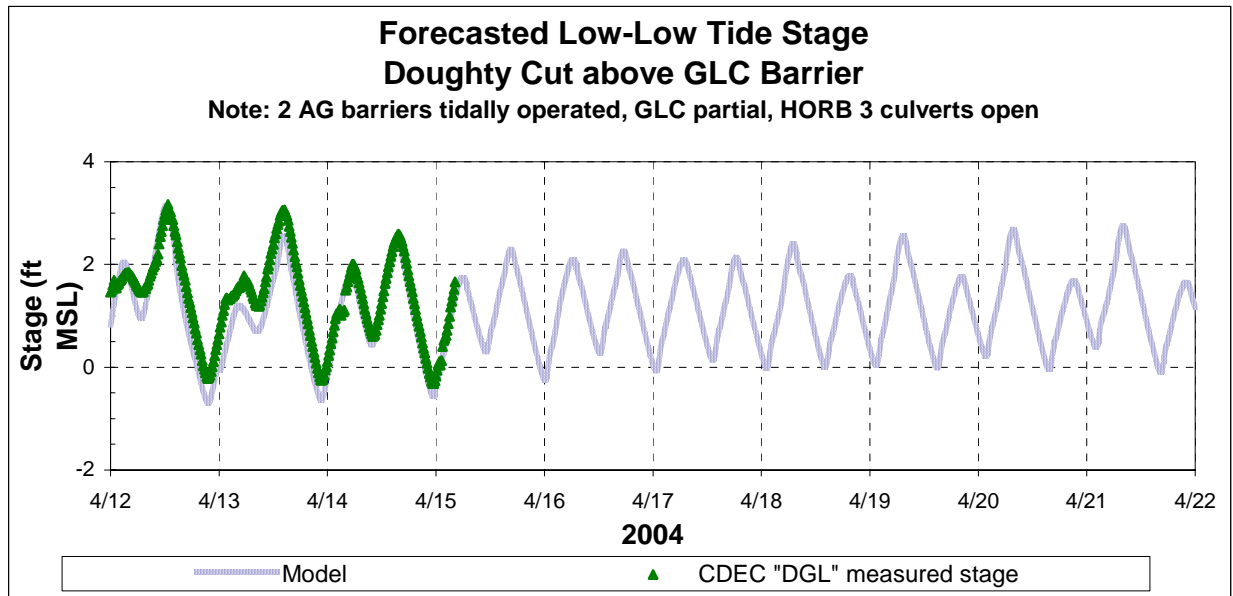
Figure 8.3: Example of Forecasted Water Levels Using DSM2.
(taken from Burns, 2004)

O&M generates these weekly forecasts by first using information on current and short-term projected water supply levels and demands to create a daily operations spreadsheet of Delta inflows and exports. The forecast flows and exports based on the spreadsheet operations along with stage estimates (Ateljevich, 2000), salinity estimates (Ateljevich, 2001), and future barrier operations are combined with hourly real-time Delta flow and operations data to produce a short-term DSM2 simulation. The length of the short-term forecast can vary depending on the purpose of the forecast. As shown in Figures 8.2 and 8.3, DSM2 was run for nearly two months in the O&M example forecast, but for only 10 days in the South Delta example forecast. The accuracy of a forecast decreases with the length of the forecast simulation. In both cases, a period of several days to several weeks in length is run before the start of the actual forecast in order to both establish initial hydrodynamic and water quality conditions prior to the actual forecast and validate model performance. This warm-up period uses real-time field data that is screened as part of a pre-processing step before beginning a model run.

At times, more than one forecast simulation is run in order to use DSM2 to help evaluate possible different Delta responses to different operation decisions. Examples of this include delaying the installation and construction of a temporary barrier by a few days, altering upstream releases and/or changing export pumping levels, or changing the operation of the Delta Cross Channel.

O&M's DSM2 Delta forecasts have shown that the DSM2 forecasting tool is effective at providing qualitative information concerning the trends in various hydrodynamic and water quality parameters. However, a more formal analysis of the ability of O&M's current DSM2-based forecasts to provide accurate quantitative results has not been conducted. It should be noted that DSM2 real-time simulations can at times fail to reproduce or predict observed data due to a combination of errors in forecast model input and DSM2 accuracy.

8.4   Forecasting Proof of Concept

Although RTDF plans to incorporate the existing O&M short-term forecasts into its water quality reports, the committee has been also developing a long-term water quality forecast (Hutton and Woodard, 2003). Suits and Wilde (2003) originally conducted a proof of concept simulation to determine whether long-term operational forecasts can provide valuable information by using old O&M monthly forecasted hydrology and operations spreadsheets from 1998 to simulate what the "forecast" EC using O&M's spreadsheet forecasts in DSM2 would have been. The forecast EC results were then compared to the 1998 DSM2 historical EC simulation. Other water quality constituents were derived as a function of EC. Suits and Wilde concluded that long-term "forecast" results were consistent with the historical simulation results for some locations and some time periods, but at other times there were significant differences in forecast versus historical simulated EC. These differences could be explained by a combination of factors, including differences in the inflows, exports, Delta Cross Channel operation, and timing of the installation and operation of south Delta temporary barriers (Suits and Wilde, 2003).

8.4.1   Expanding the Delta Water Quality Forecast Proof of Concept

Based on the initial findings of the above study, an extended proof of concept simulation that examined the significance of different exceedence level forecasts and two additional years, was conducted. Long-term O&M January, March, and May operations spreadsheets from 1998, 1999, and 2000 were used to conduct 23 different DSM2 forecasts (see Table 8.1). Each month, O&M uses the water supply outlook forecasts to develop multiple monthly hydrology and operations spreadsheets for each month based on different probabilities of water supply. These different probability-based forecasts are called "exceedence levels". Different exceedence level forecasts have different inflows and exports. By running multiple exceedence level DSM2 forecasts for the same month, a range of expected water quality results can be provided.

Table 8.1: Summary of O&M Forecasts Used in DSM2 Proof of Concept.

		Forecast Exceedence Level		
Forecast Start Date		$50^\%$	$75^\%$	$90^\%$
1998	January	✓	✓	✓
	March	✓	✓	✓
	May	✓	✓	✓
1999	January	✓	Not available	✓
	March	✓	Not available	✓
	May	✓	Not available	Not available
2000	January	✓	✓	✓
	March	✓	✓	✓
	May	✓	✓	✓

The water supply outlook forecasts are based on the unimpaired runoff from the watersheds that provide the SWP with its water and are described as exceedence probabilities. An example of the exceedence probabilities associated with the historical unimpaired Sacramento River Valley runoff is shown in Figure 8.4. Higher exceedence probabilities are associated with drier events (i.e. lower runoff). In this example, the 50% percentile exceedence probability is associated with normal conditions (i.e. an unimpaired runoff of 16.7 maf), while the 90% percentile exceedence probability is associated with drier conditions (unimpaired runoff of 8.2 maf).

The O&M long-term operational forecasts take into account current conditions. They can be generalized as moving from anticipated real-time conditions to more generalized historical patterns. A forecast of March conditions made in February will tend to be more accurate than a one made in January.
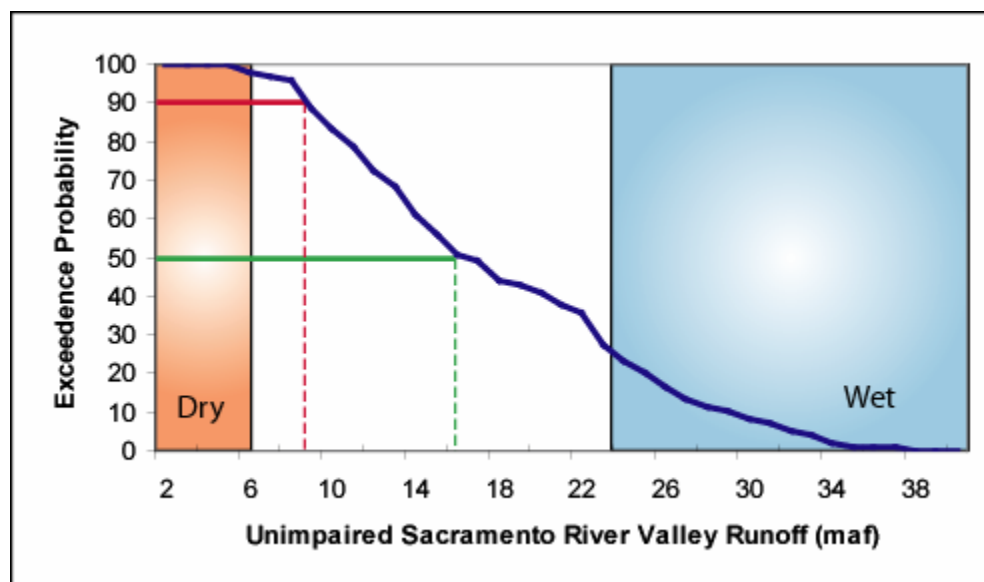
Figure 8.4: Example of Forecast Exceedence Levels.

Table 8.2: Example of Inflows into Lake Oroville from the 1998 Operations Forecasts.

	January Forecast Exceedence Probability			March Forecast Exceedence Probability		
	50%	75%	90%	50%	75%	90%
Jan	5,490	4,147	15,563 *	-	-	-
Feb	8,503	6,224	4,441	-	-	-
Mar	7,798	7,091	5,282	16,231	14,783	14,426
Apr	9,439	8,127	6,155	15,209	13,243	12,352
May	7,347	6,314	4,734	14,149	11,693	10,897
Date of Forecast	11/24/97	12/15/97	1/1/98	3/9/98	3/9/98	3/27/98

An example of O&M inflows into Lake Oroville is shown in Table 8.2. In this example, three different forecasts were made starting in January 1998 and three additional forecasts were made starting in March 1998. In general, forecast flows into Lake Oroville decrease with increasing exceedence probability levels. An exception is the January 1998 90% exceedence level for the January forecast. The other months for the January forecast follow the usual trend, but the 90% January flows into Lake Oroville are 10,000 cfs greater than the 50% exceedence level because the 50% exceedence flows were forecast in December while the 90% exceedence level flows were forecast in January.

8.4.2 Executing the Delta Proof of Concept

Although the historical DSM2 base-line study was run from 1990 through 2002, the initial conditions for each forecast were taken by stopping the DSM2-QUAL historical simulation on the start date for each group of forecast simulations: Jan. 1st, Mar. 1st, and May 1st, 1998 and applying the exact model state (i.e. model results) to the forecast start (see Figure 8.5). The Jan. 1st forecasts ran from Jan. 1st through Dec. 31st, 1998. Similarly, the Mar. 1st forecasts ran from Mar. 1st through Dec. 31st, 1998, and the May 1st forecasts ran from May 1st through Dec. 31st, 1998. The results of all of the 1998 simulations were compared to 1998 simulated historical EC. This process was repeated for the 1999 and 2000 forecasts.
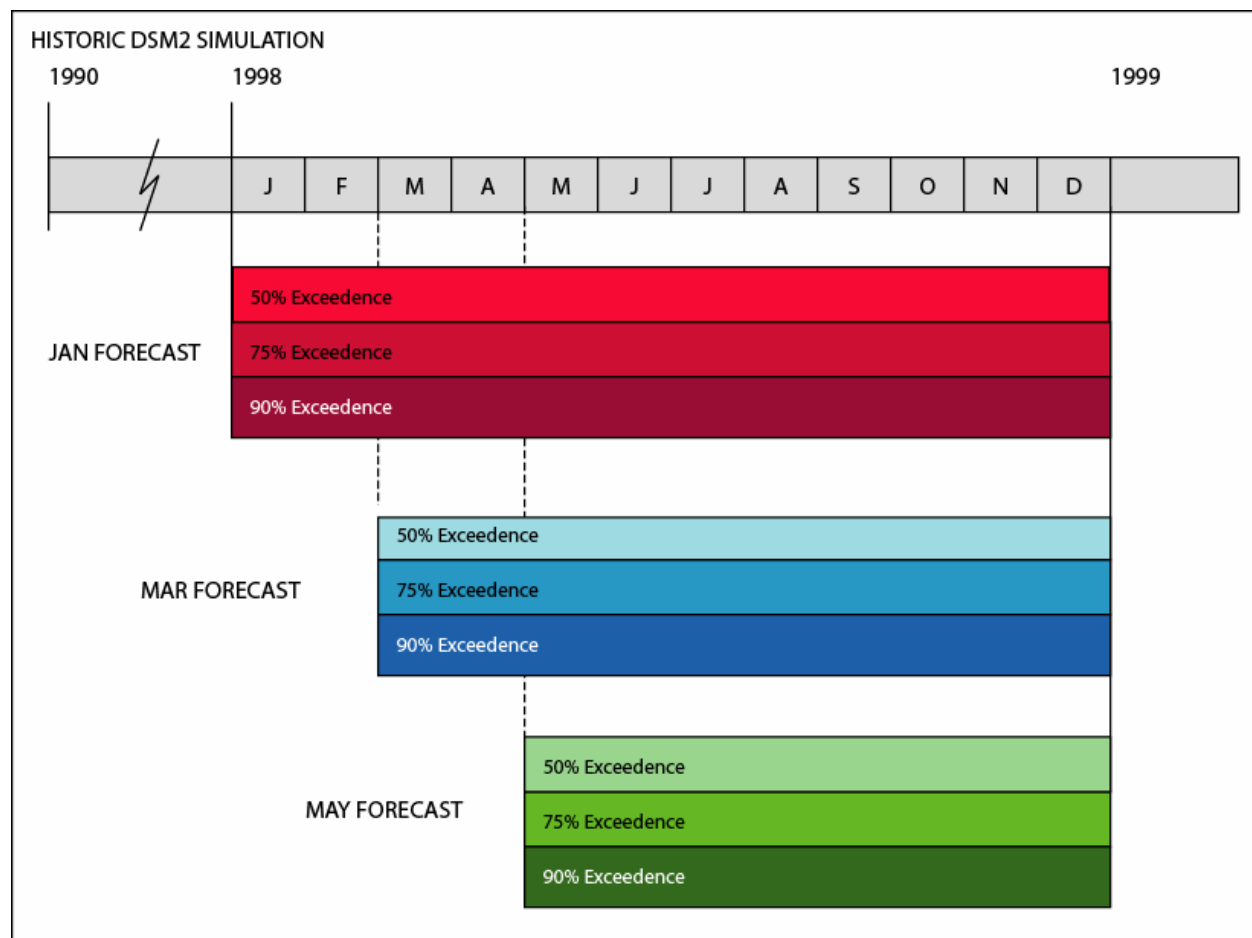

Figure 8.5: Time line for 1998 "Forecast" Proof of Concept DSM2 Simulations.

Since the goal of the proof of concept was to test the value of forecasting water quality associated with long-term operations forecasts, only the flow data that is presented in the O&M operational and hydrologic forecasts was used in the DSM2 forecasts. These spread sheets include the major Delta inflows and exports and estimated Delta consumptive use.

Flows / Exports

The flow inputs to the Delta included the Sacramento River, the San Joaquin River, and the Eastside Streams (which includes the Mokelumne and Cosumnes Rivers). The monthly flows for the Sacramento and San Joaquin Rivers were converted into daily values using a mass conservative spline in order to smooth out any steep changes in monthly averaged flow. Monthly Eastside Streams flows were taken directly from the O&M spreadsheet.

Exports from the Delta included: the State Water Project (SWP) Banks Pumping Plant, Central Valley Project (CVP) Pumping Plant, and Contra Costa Water Districts' (CCWD) combined diversions. The CCWD diversions were considered to occur at Rock Slough Pumping Plant #1.

Operation of Delta Structures

The Delta Cross Channel (DCC) operation is included in the O&M spreadsheet forecasts in terms of the percentage of time open each month. The operation of the DCC in the field is determined by both Sacramento River flow and the time of year. The O&M spreadsheets took into account the rules that govern the operation of the DCC; thus, if the forecast Sacramento River flows were higher than the flows in either the historical or other forecast simulations, a different operation of the DCC could potentially affect the internal Delta circulation patterns and salinity movement.

The installation and operation of south Delta temporary agricultural barriers in Old River, Middle River, and Grant Line Canal and the fish protection barrier at the head of the Old River are dependent upon the time of year and the flow in the San Joaquin River. Like the operation of the DCC, deviations in the forecast San Joaquin River flows between the historical and other forecast simulations, such as the high flows associated with the 1998 historical simulation, could lead to significant differences in flow patterns in the south Delta.

Consumptive Use

The forecast total Delta consumptive use was used to create forecast Delta island diversions and return flows using the Adjusted Delta Island Consumptive Use (ADICU) model. A unique set of Delta island diversions and return flows was calculated for each forecast simulation; for example, the consumptive use data used for the Jan. 50% exceedence forecast was different than the consumptive use data use for the Jan. 75% exceedence forecast.

Stage

The DSM2 forecasts were treated as if Martinez stage was unavailable available during the 1998 through 2000 period. For short-term forecasts, a tool is used to blend real-time stage observations to an astronomical modeled stage (Ateljevich, 2000); however, after a few days, a pure astronomical modeled stage is applied at Martinez. This astronomical stage was used for the seasonal forecasts.

EC

Daily EC for the San Joaquin River at Vernalis (the upstream boundary for DSM2) was calculated based on observed regressions between San Joaquin flow and EC (Suits and Wilde, 2003). Ocean salinity was calculated using a modified G-model with O&M forecast monthly net Delta outflow and the astronomical tide as inputs. The EC associated with inflows from the Sacramento River and Eastside Streams was kept constant throughout the entire forecast period.

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8.4.3 Water Quality Results of Proof of Concept in the Delta

Modeled EC at the SWP Banks Pumping Plant for the 50% exceedence level forecast for the 1998, 1999, and 2000 simulations and the simulated historical EC are shown in Figure 8.6. The difference between the forecast and historical results varies from month to month for all three years. At times the results of the simulations match well, such as in the case of the May 1998 50% exceedence level forecast. However, there are also times when the results of the forecast and historical simulated EC diverge. An example of one such period is November through December 2000 when the forecasted hydrology did not account for early winter storms and higher Delta flows.
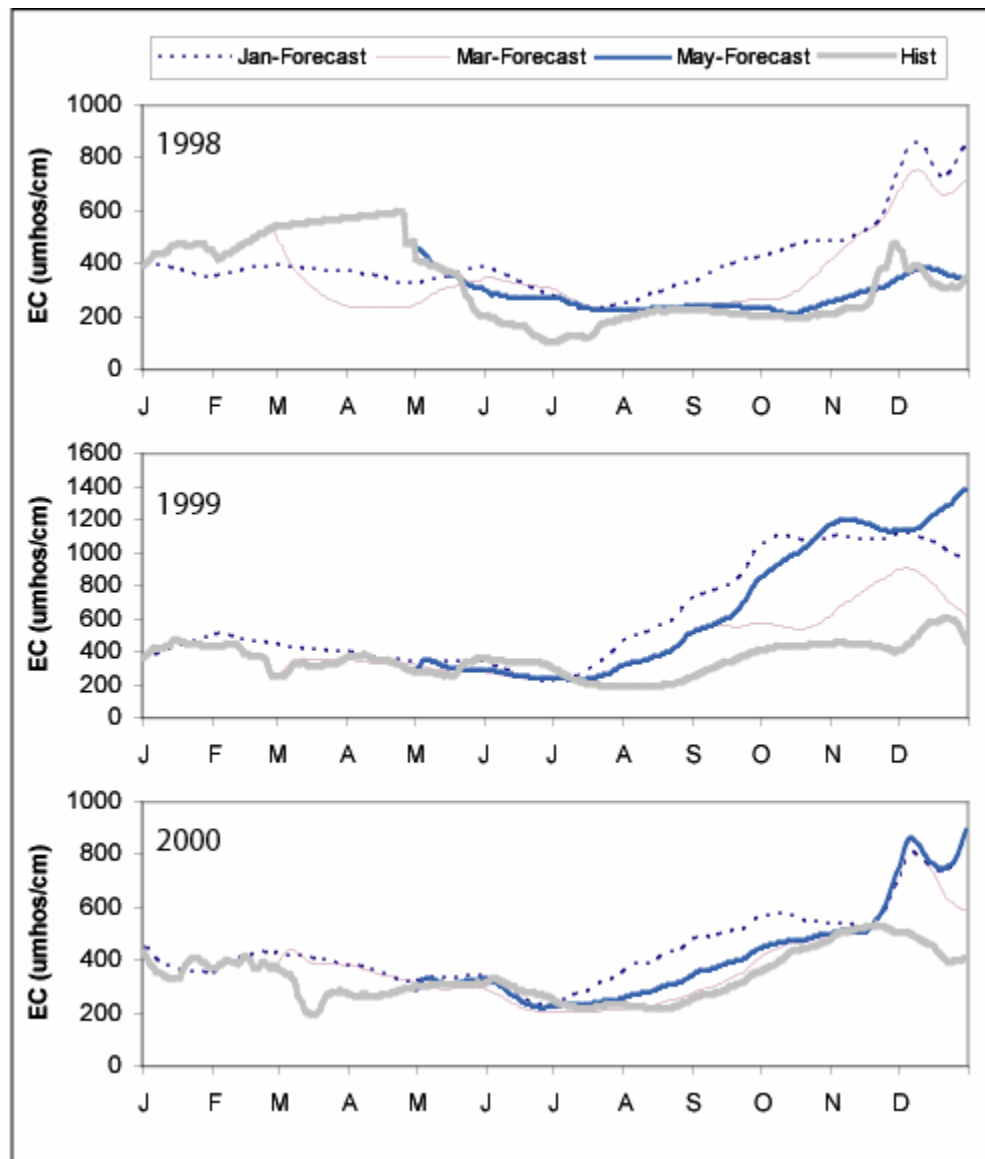
Figure 8.6: EC at Banks Pumping Plant (SWP) for DSM2 Historical Simulation and Nine DSM2 50% Exceedence Level Long-Term Forecasts.

8.4.4 Extending the Proof of Concept to the California Aqueduct

Since the RTDF committee is concerned with the quality of water that is delivered to the water contractors, the original proof of concept consisted of a Delta component (Suits and Wilde, 2003) and the California Aqueduct (Liudzius, 2003). SWP Banks Pumping Plant and CVP Tracy Pumping Plant EC results from the 1998 three 50% exceedence level DSM2 forecasts: January, March, and May, the 1998 historical simulation, and an O&M forecast that included the operations for the California Aqueduct were used as the input in two daily time step models:

❑ O'Neill / San Luis Model – blends water in the O'Neill Forebay, and
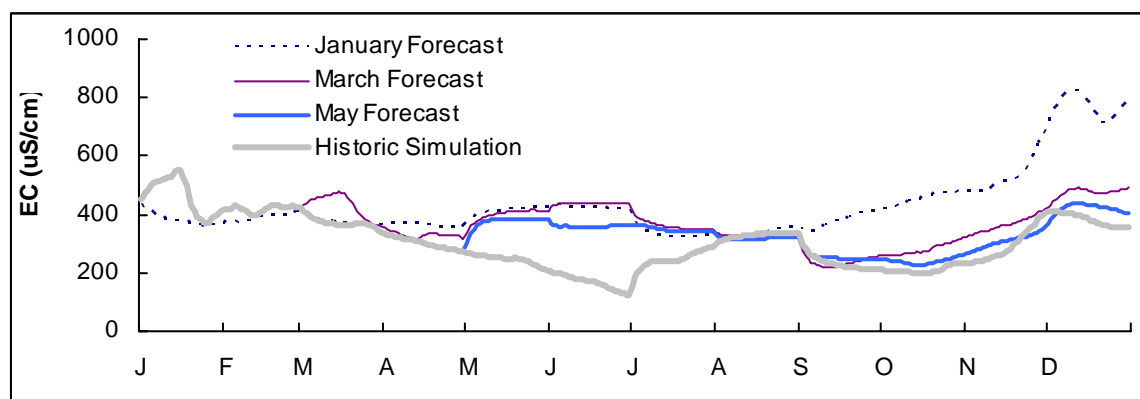❑ California Aqueduct Model – simulates water downstream of O'Neill Forebay.

Since inflows to the O'Neill Forebay come from three sources: California Aqueduct, the CVP's Delta Mendota Canal, and releases from San Luis reservoir, Delta water was blended with the San Luis releases before being used as input into the California Aqueduct Model (Liudzius, 2003).

The 1998 O&M forecasts did not include all of the input data required by the California Aqueduct Model, therefore assumptions were made to estimate some of the demands and diversions along the California Aqueduct (Liudzius, 2003). Liudzius adopted an approach to estimate South of Delta demands and inflows by maintaining an overall water balance and then making estimates based on historical operations and use patterns. These estimates took into account physical limitations.

1998 EC at the O'Neill Forebay outlet for the Metropolitan Water District's California Aqueduct Model for the three 50% exceedence level forecasts and the historical simulation are shown below in Figure 8.7. Liudzius (2003) pointed out that the results at downstream locations along the California Aqueduct generally follow the trend of water quality predicted by DSM2 at the SWP intake and to a lesser degree the trends of the DMC intake. Again, the California Aqueduct extension proof of concept indicates that developing and conducting long-term water quality forecasts is promising. However, further study in how accurate forecasts of fall Delta inflow needs to be in order to obtain useful forecast EC at the SWP remains to be investigated.

Figure 8.7: EC at O'Neill Outlet for MWD California Aqueduct Model Based on DSM2 Historical and Long-Term Forecast Simulations.
(taken from Liudzius, 2003)

8.5 Short- vs. Long-Term Forecasts

Two types of water quality forecasts that have been discussed: weekly (short-term) – O&M production Delta water quality and stage forecasts, and seasonal (long-term) – Delta and California Aqueduct proof of concept work. Each type of water quality forecast can be used to answer different questions. Generally, the short-term forecasts are used to answer immediate operations needs, but since these forecasts are typically limited to simulating 1 to 2 months, they have little value for making long-term operational decisions. In contrast, the seasonal (long-term) forecasts make less use of real-time field data, but can be used to address possible management decisions several months in the future.

In the example shown in Figure 8.8, two forecasts start on Feb. 27. The weekly forecast ends three weeks later, while the seasonal forecast continues through Dec. 31. Although the weekly forecast incorporates real-time field data into its initial conditions, as the simulation moves further away from the Feb. 27 start data, the weekly forecast values approach the accuracy of the values used in the seasonal forecast. In other words, there is no real benefit to extending the weekly forecast beyond a month or two.
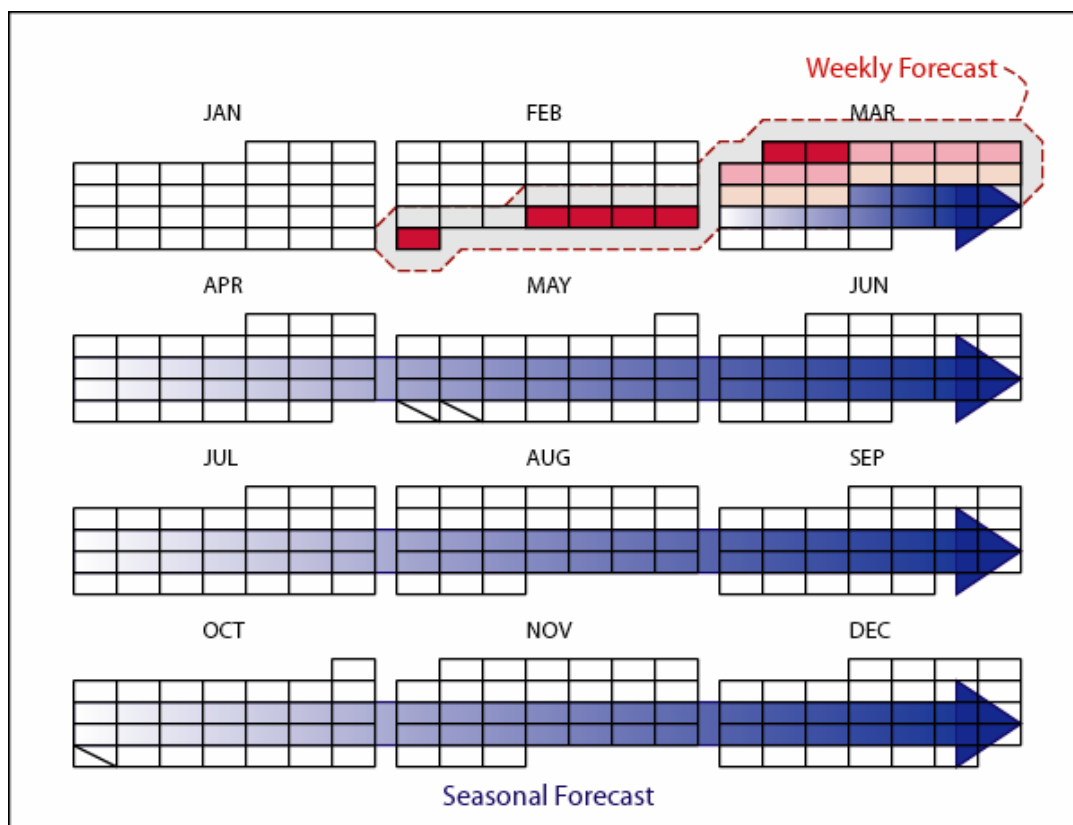
Figure 8.8: Time Frame of Short- (Weekly) vs. Long-Term (Seasonal) Forecasts.

8.5.1 Differences Between Weekly and Seasonal Forecasts

The primary differences between the weekly and seasonal forecasts are listed in Figure 8.9. The weekly forecasts are used to forecast water quality at the urban intakes and south Delta stage, while the seasonal forecasts usually focus solely on water quality at the urban intakes. When the seasonal model is coupled with MWD's O'Neill / San Luis and California Aqueduct models, water quality in the California Aqueduct is also simulated. O&M typically uses a single forecasted daily hydrology per weekly DSM2 simulation, but has used the model to produce multiple forecasts for the same time frame by changing the modeled operation (i.e. by changing the installation / removal dates or the position of tidal flap gates) of the south Delta temporary barriers. In contrast, the use of the seasonal model has focused on examining the long-term trends associated with different exceedence level forecasts.

Since the short-term forecast is concerned with accurate short-term results, it is necessary to transition from the real-time (historical) tidal boundary condition into a forecast tide. The method for doing this has been proven to be accurate, but within a month, the tidal boundary condition is completely based on the astronomical tide, changing from the historical tide.

WEEKLY	SEASONAL

Output:
- South Delta: Stage & Water Quality
- Urban Intakes: Water Quality
 	
Hydrology:
- Single Forecast
- Daily Flows
 	
Ocean Boundary:
- Historic transitions to Astronomical
 	
Barriers:
- Operations based on Expected
  Construction Schedules / Contracts
	Output:
	- Urban Intakes: Water Quality
	- California Aqueduct: Water Quality
	
	Hydrology:
	- Multiple Exceedence Forecasts
	- Monthly Flows
	
	Ocean Boundary:
	- Astronomical
	
	Barriers:
	- Operations based on Previous
	  Operations and Design

Figure 8.9: Comparison of Weekly vs. Seasonal Forecasts.

Although the seasonal forecast from water quality uses a real-time historical simulation to generate initial conditions, the hydrodynamic simulation in a seasonal forecast is uncoupled from the real-time data. There is no point in transitions real-time stage data into an astronomical

model when the decisions made using the seasonal forecast will likely extend beyond the influence of the observed tidal data. Instead, a pure astronomical based tide is used.

Finally, the methodology used to operate the barriers and gates in the Delta is different between the two forecasts. In weekly forecasts, the planned operation of the barriers is available via scheduled installation or removal contracts. However, since it is difficult to foresee the exact timing of the scheduled construction or operation of a barrier or gate months in advance, the general operating rules for all of the Delta structures are determined based on time of year and forecast flows and are consistent with assumptions in planning studies connected to CALSIM output. The process used to govern seasonal gate and barriers operations under hypothetical San Joaquin inflows is described in more detail in Suits and Wilde (2003).

8.5.2 Seasonal Methodology

The methodology used to simulate just the flows and water quality in the expanded Delta proof of concept (see Section 8.4.2) is illustrated below in Figure 8.10. This methodology will be used in future Delta seasonal forecasts as well, but does not include the process used to model the California Aqueduct.
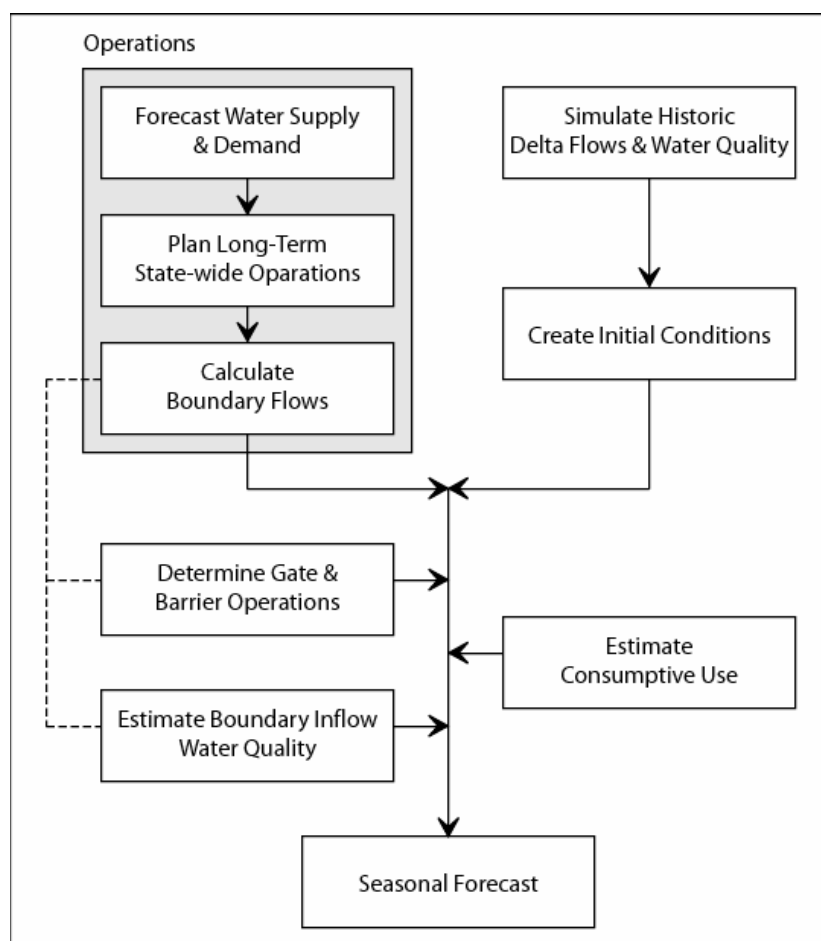
Figure 8.10: Seasonal Forecast Methodology.

Seasonal forecasting in the Delta can be described by four primary tasks: generating an operations forecast, generating corresponding forecast boundary conditions, updating the real-time (historical) simulation in the Delta, and then combining the operations forecast with the real-time historical simulation. The seasonal forecasts typically begin on the first of a month and continue through the end of the calendar year. Historical simulations are only used to generate the initial water quality throughout the Delta. Currently, DSM2 forecasts are limited to simulating EC, which is sometimes converted to TDS and bromide using the EC results.

O&M already forecasts water supply and demand when creating long-term state-wide operations. The boundary flows into the Delta can be taken directly from the O&M long-term operations forecasts. The operation of gates and barriers and the EC at the Delta boundaries are calculated using the O&M boundary flows. The O&M long-term operations forecasts estimate the net Delta consumptive use, which is then distributed to represent various island diversions and return flows based on the ADICU model.

8.5.3 Weekly Methodology

The original methodology described by Mierzwa (2001) is still being used by O&M when conducting weekly forecasts. However, the pre-processing and post-processing methods have been slightly modified. First, the MS Access Forecast form is not being used to convert the MS Excel spreadsheet based forecasts into the DSS time-series format for DSM2 use. Instead of using the GUI, the spreadsheet based forecasts are converted into DSS using scripts. Next, the data for each forecast is not being saved on a central server. This means that different users will not be able to share forecasting input.

Typically weekly forecast results are used in adjusting current field operations, thus the most pressing need of the DSM2 short-term forecasting system is to produce valuable results in short order. Although some of the original GUI based tools were developed with repeatability in mind, they are not as timely to use as simple scripts.

8.6 Development Tasks

Understanding that the O&M weekly forecasts have been adapted to facilitate short-term decision and operations support, but also recognizing the value illustrated in the long-term seasonal forecasts to longer term planning, RTDF has decided to improve both the existing weekly forecasting and develop a ready-to-use seasonal forecasting tool. For both the weekly and seasonal forecasts, the major development phases and the milestones associated with the completion of each of these phases are listed in Figures 8.11 and 8.12.

Figure 8.11: Future Development Phases and Milestones for Weekly DSM2 Forecasts.

Figure 8.12: Future Development Phases and Milestones for Seasonal DSM2 Forecasts.

Most of the development associated with the weekly forecasts can be directly used in the seasonal forecasts. The primary difference between the two forecasting approaches lies in the earlier development phases. The milestones associated with each of the phases are described below.

8.6.1 Phase 0: Existing Production Runs / Proof of Concept

Currently, O&M is using DSM2 weekly forecasts to aid in adjusting operations in order to meet Delta salinity standards. These same DSM2 forecasts are used by the Temporary Barriers and Lower San Joaquin Section to disseminate information on forecast water levels to the public.

This phase represents the on-going work associated with both forecasting systems. When needed, EC results from either model are simply being converted to TDS or bromide based on relationships between those constituents and EC. Development work on this phase is finished.

8.6.2 Phase 1: Basic Improvements / Regular Updates

Fingerprinting is the methodology used to determine the relative contributions of water sources to either a total volume or water quality constituent concentration at a specified location (Anderson, 2002). Although fingerprinting results have been integrated into the seasonal forecasts, they have not yet been incorporated into the weekly forecasts. The key to producing meaningful short-term source water fingerprints is finding a way to estimate the initial conditions prior to starting the forecast run. Initial source water fingerprints are conceptually no different than finding the initial EC conditions for a DSM2-QUAL run. Any water quality constituent initial condition can be found by assuming a uniform initial concentration of zero for all constituents and allowing mixing over the course of several months to distribute and blend the concentrations associated with the boundary inflows throughout the Delta. This process is often referred to as a cold start.

The length of time required for complete mixing can be measured by checking for the conservation of mass for a series of volumetric fingerprints. The general fingerprinting methodology introduced by Mierzwa and Wilde (2004) was modified for use in the improved proof of concept (see Section 8.4.1). The volumetric fingerprints found that the minimum length of time required for complete mixing, which is necessary for a cold start initialization, depends not only on the time of year (start date of a forecast), but on the flows associated with the start date. In general, drier conditions require longer cold start initialization periods ranging from 2 to 4 months.

Fingerprinting in both forecasts will be accomplished by continually updating the historical DSM2 simulation and using the final state of its water quality constituents as the initial conditions for the forecasts. Since the historical simulation goes back to 1990, achieving a long enough simulation to account for complete mixing will be simple. Each update of the historical simulation will be appended to the previous historical updates.

Finally, the RTDF will work to facilitate both regular updates to the historical and forecast simulations in addition to standardizing the results of the DSM2 forecasts. Forecast results will be included in MWQI's water quality update.

8.6.3 Phase 2: Develop Aqueduct Model

Simultaneous to the work on streamlining the dissemination of forecast results and inclusion of fingerprinting, work has already begun on determining the data needs and design of a California Aqueduct extension for forecasting. This phase is focused on determining the data necessary to model the aqueduct and developing a communication network to ensure that real-time data and forecasts for SWP demands and deliveries will be available for later work when the Aqueduct model is coupled to DSM2.

8.6.4 Phase 3: Improved TDS & Bromide

TDS and bromide forecast results were estimated by converting modeled EC results using TDS / EC and bromide / EC relationships. These relationships were developed for different Delta urban intakes. The regressions used to convert EC into TDS and bromide will be improved and can make use of the fingerprinting results that will be available after the completion of Phase 1.

8.6.5 Phase 4: Direct TDS & Bromide Simulation

Using the improved TDS and bromide regressions developed in Phase 3, it will be possible to apply those boundary conditions directly into DSM2 and begin the process of re-calibrating and validating DSM2 for these constituents. A cold start process similar to that discussed above in Phase 1 (see Section 8.6.2) can be used to determine the initial TDS and bromide conditions in production forecast simulations. Nonetheless, modifications to the current EC warm start routine will also allow the weekly forecasts to directly simulate TDS or bromide in the same manner that they currently simulate EC.

8.6.6 Phase 5: Forecast Organic Carbon (short-term only)

Though there is a strong interest in forecasting the concentration of organic carbon in the SWP system, peak organic carbon concentrations in the Delta are highly correlated with early winter runoff events. The ability to forecast the increase of organic carbon in the Delta is tied to the ability to accurately forecast the approximate date of the early storm events. Although it may be possible to produce meaningful short-term organic carbon simulations based on precipitation forecasts, seasonal forecasting will be problematic in the first months since significant flows in the Sacramento and San Joaquin rivers originate from overland flow instead of reservoir releases. Instead, the focus of this phase will be to develop accurate flow / precipitation – organic carbon relationships that can be used to recreate the historical boundary conditions and forecast the future boundary conditions necessary for short-term weekly organic carbon forecasts.

8.6.7 Phase 6 / 5: Couple DSM2-Aqueduct Extension

Building upon the work of Phase 2, a stand-alone DSM2-Aqueduct model is being developed by CH2M-Hill. The model can be run independently from DSM2 or linked to DSM2 as needed. It will need to use of California Aqueduct forecasts, including aqueduct demands and deliveries. The basic development of this model is schedule to be completed by the end of 2004.

8.6.8 Phase 7 / 6: Couple DSM2-SJR Extension

The last development task to meet the immediate RTDF forecasting goals will be to investigate the data availability of flow and water quality information upstream of Vernalis in order to extend the DSM2 forecasting system to the San Joaquin River. Like the DSM2-Aqueduct extension, the DSM2-SJR extension can either be used with the DSM2 forecasts as a stand along model or an extension. By including the San Joaquin River in the forecasts, the regressions used to relate water quality constituents to flow at Vernalis can be replaced by simulations that account for variable source water and associated water quality characteristics.

8.7 Conclusions

The seasonal forecasting proof of concept work in the Delta and along the California Aqueduct combined with the usefulness of the weekly DSM2 Delta forecasts have shown that there may be value in developing parallel water quality forecasting systems for the SWP system. The focus of the weekly forecasts already is and will continue to be to aid short-term operations decision making, and RTDF will continue to develop a long-term seasonal forecasting system whose potential for providing useful information to water managers will be further investigated.

8.8 References

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Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

25th Annual Progress Report
October 2004

Chapter 9:
Using QUAL Fingerprinting Results to Develop DOC Constraints in CALSIM

Author: Michael Mierzwa and Jim Wilde

9 Using QUAL Fingerprinting Results to Develop DOC Constraints in CALSIM

9.1 Introduction

DWR's statewide operations model (CALSIM) uses an Artificial Neural Network's (ANN) flow relationships to estimate Delta salinity impacts due to its decisions. However, special flow-based constraints need to be programmed into CALSIM if its operations are to take into account other water quality constituents, such as dissolved organic carbon (DOC), or if different Delta geometry is to be studied. Prior CALSIM / DSM2 In-Delta Storage (IDS) studies have used DSM2's ability to track particles with DSM2-Particle Tracking Model (PTM) to develop flow-based DOC constraints for CALSIM II (Mierzwa, 2003a and 2003b). Because of limitations in the previous PTM-based island particle fate - flow relationships, a methodology using DSM2-QUAL fingerprinting was developed to replace the PTM-based approach.

The concept behind both approaches is to develop a flow-based regression that can answer the following question:

> *How much organic carbon from the IDS project islands reaches the urban drinking water intakes?*

This question can be answered by using DSM2 to estimate the volume of water from the islands that reaches the urban intakes and then developing relationships between volume and various flow parameters. The point of this exercise is to examine these various relationships and then determine which one is most useful.

Similar to the particle fate information provided by PTM, QUAL fingerprints estimate the original sources of water at a given location (Anderson, 2002). The previous PTM-based approach had the following limitations:

❑ Non-release periods were not simulated (even though the equations were used for all time periods),
❑ Each release period required a separate simulation for each island,
❑ Particle fate information was extracted only at the end of each 30-day day PTM simulation, and
❑ Particles were only released during the first 24-hour period of the simulation.

These limitations were addressed in the new QUAL approach. Daily average fingerprinting results were used to develop relationships between daily percent volume of project island water at an urban intake and flow in the Delta that could be easily used by the CALSIM II Daily Operations Model. This chapter describes the methodology used to fingerprint and develop these relationships. The actual CALSIM constraints are not described in this report.

9.2 IDS Background

DWR's Integrated Storage Investigations' (ISI) IDS project linked CALSIM with its Delta hydrodynamics and water quality model (DSM2) in order to evaluate the changes in Delta water quality due to releasing water from the two proposed IDS reservoir islands, Bacon Island and Webb Tract (see Figure 9.1). The goal of the IDS project was to use the two islands as storage facilities to increase drinking water supply while maintaining environmental standards. In order to meet this goal, it was necessary for CALSIM and DSM2 to be used in an iterative process, where CALSIM output was used to generate boundary conditions for DSM2 which was subsequently run to generate Delta water quality conditions. Relationships developed based on the DSM2 fingerprinting results were used to develop constraints for new CALSIM simulations.
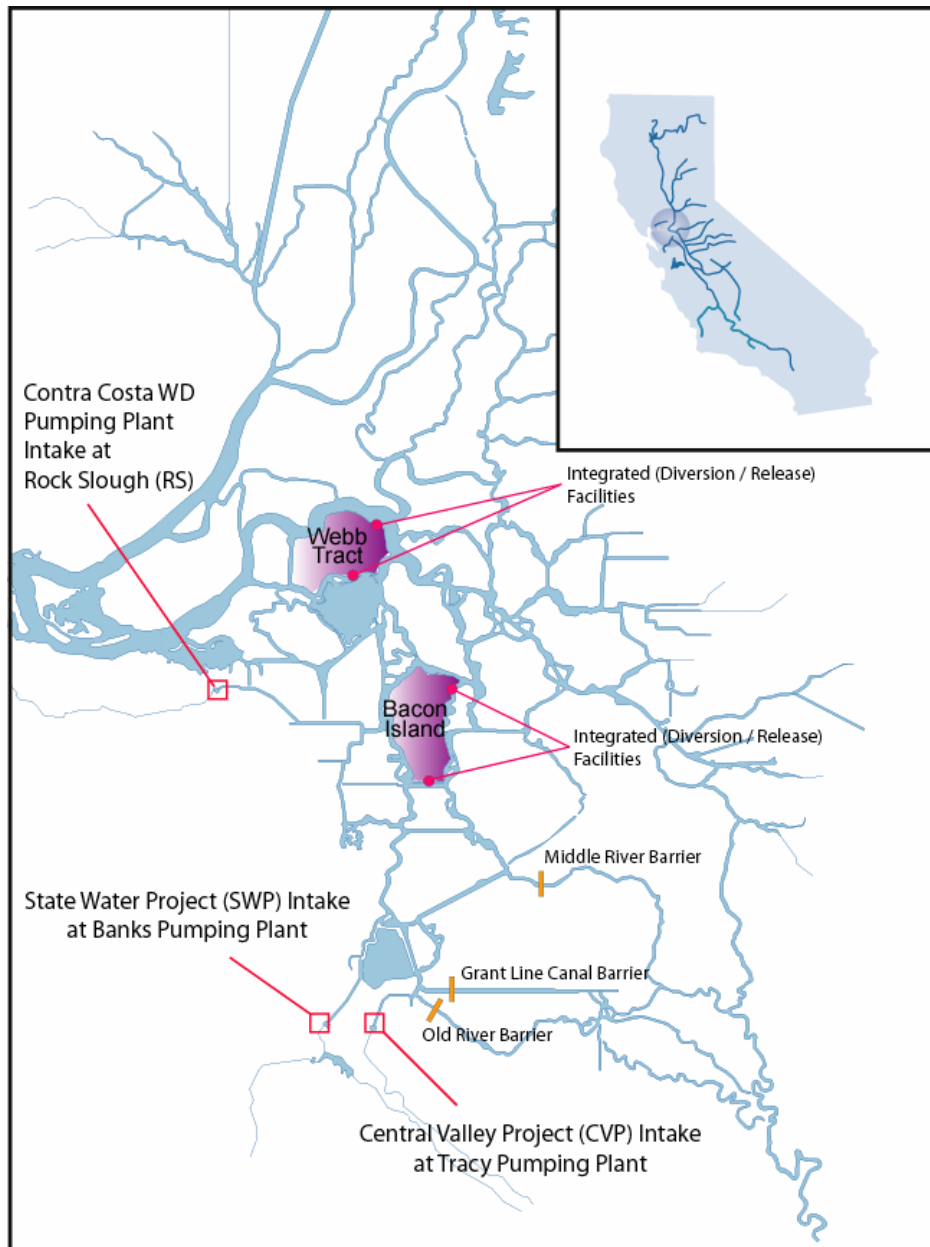
Figure 9.1: Location of Project Islands and Urban Intakes.

As described above (Section 9.1) previous CALSIM-DSM2 DOC constraints were based on an iterative process in which CALSIM provided the operations input to DSM2-HYDRO, and then DSM2-HYDRO's hydrodynamics were used in a series of multiple DSM2-PTM simulations (Mierzwa, 2003a and 2003b). Limitations in the PTM approach lead to using DSM2-QUAL instead of PTM to estimate the amount of water from each of the islands that would reach three nearby urban drinking water intakes: Contra Costa Water District's Rock Slough (RS), the State Water Project's (SWP) Banks Pumping Plant, or the Central Valley Project's (CVP) Tracy Pumping Plant intakes. CALSIM treated Contra Costa Water District's RS and Los Vaqueros Reservoir (LVR) intake diversions as a single node. Since DSM2 did not separate the CALSIM Contra Costa Water District (CCWD) point of diversion to both RS and LVR, no relationship for flow reaching LVR was developed.

9.3 Methodology to Develop Fingerprinting Based Constraints

Using fingerprinting to develop relationships between the volume of water percentage from the island and the Delta flow was a three-step iteration. These relationships were developed based on the results of the second step (i.e. first iteration) of the process. Only the second step involved fingerprinting results. All three steps are shown in Figure 9.2 and described in more detail below.
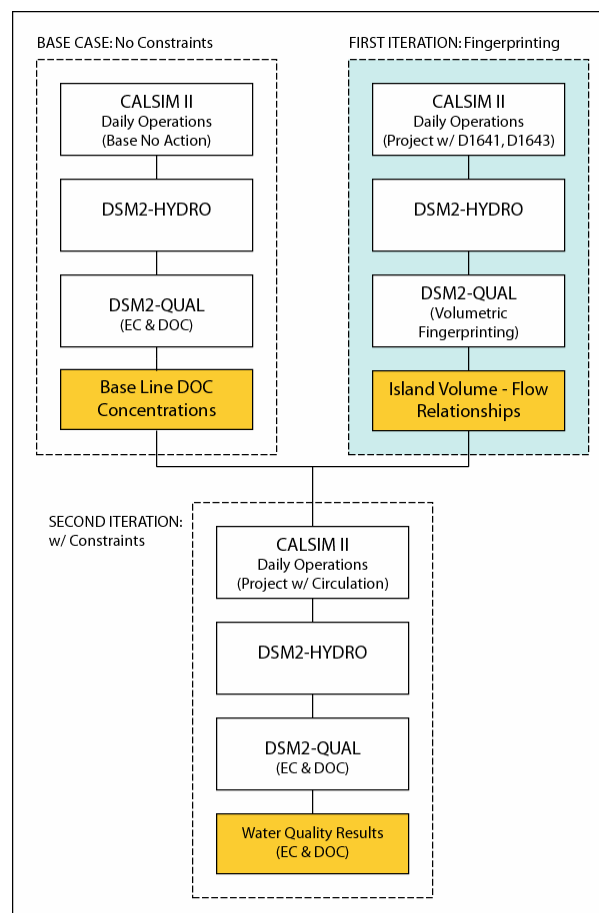
Figure 9.2: Fingerprinting Study Methodology.

9.3.1 Base Case: No Constraints

CALSIM calculated a base case operation of the SWP / CVP system without the presence of the IDS project islands. Since there were no project islands, there was no need for including any DOC constraints on these initial CALSIM simulations. The CALSIM results were then used in HYDRO to generate the stage and flow patterns in the Delta. In turn, the HYDRO results were applied to QUAL to calculate the base line organic carbon concentrations of water in channels adjacent to the islands and at the urban intakes (RS, SWP, and CVP). These results were later used in combination with the fingerprinting-developed relationships developed in the first iteration to form the basis of the DOC constraints in CALSIM.

9.3.2 First Iteration: Fingerprinting

In the first iteration, the IDS project islands were added to the CALSIM simulation, but no organic carbon constraints were used by CALSIM. CALSIM would divert water onto the islands or release water from the islands without considering the impact of these releases on organic carbon loadings at the urban intakes. Stage and flow patterns in the Delta and the diversions and releases from each intake / release facility were modeled in HYDRO. QUAL was then used to calculate the volumetric fingerprint of water at the three urban intakes: RS, SWP, and CVP (see Figure 9.1).

Volumetric fingerprint (Anderson, 2002) studies were used to calculate the percentage of water from each source at a single point of interest. In order to apply a fingerprint to each source of water, it was necessary that every source inflow, including the project island releases, be introduced as a new source. The QUAL fingerprint was applied to this source of water by assigning a unique conservative tracer constituent to it. The sources modeled included: the Sacramento River, San Joaquin River, Yolo Bypass, Eastside Streams (which is treated as a single source in CALSIM), Martinez, Bacon Island, Webb Tract, and agricultural return flows from all other Delta Islands.

Though CALSIM provided separate timeseries for each island's releases and diversions, the IDS plan called for two facilities on each island. Since DSM2 was capable of modeling these two facilities, the CALSIM operations were divided between each island's northern and southern integrated facilities (Figure 9.1) by the following rules:

Diversions	Releases
If $\text{Div}_{CALSIM} > 2250$ cfs Then	If $\text{Rel}_{CALSIM} > 2250$ cfs Then
$\quad\text{Div}_{SouthDSM2} = 2250$ cfs	$\quad\text{Rel}_{NorthDSM2} = 2250$ cfs
$\quad\text{Div}_{NorthDSM2} = \text{Div}_{SouthDSM2} - \text{Div}_{CALSIM}$	$\quad\text{Rel}_{SouthDSM2} = \text{Rel}_{NorthDSM2} - \text{Rel}_{CALSIM}$
Else	Else
$\quad\text{Div}_{SouthDSM2} = \text{Div}_{CALSIM}$	$\quad\text{Rel}_{NorthDSM2} = \text{Rel}_{CALSIM}$

where,

Div_{CALSIM}	= CALSIM Total Island Diversion (cfs),
$Div_{SouthDSM2}$	= DSM2 Diversion at Island's Southern Facility (cfs),
$Div_{NorthDSM2}$	= DSM2 Diversion at Island's Northern Facility (cfs),
Rel_{CALSIM}	= CALSIM Total Island Release (cfs),
$Rel_{SouthDSM2}$	= DSM2 Release at Island's Southern Facility (cfs), and
$Rel_{NorthDSM2}$	= DSM2 Release at Island's Northern Facility (cfs).

The above project island integrated facility operation rules can be generalized to state that the majority of the project diversions were taken from each island's southern facility, while the majority of the project releases occured at each island's northern facility. The project islands themselves were not modeled since the goal of the fingerprinting simulation was only to estimate the volume of project island water that reached the urban intakes.

The last step in the first iteration was to use the QUAL volumetric fingerprinting results in order to develop island volume - flow relationships for each of the three urban intakes. These relationships along with the DOC results from the base case simulation formed the CALSIM DOC constraints. The fingerprinting results are briefly discussed below (Section 9.4) and the relationships derived from them are described in Section 9.5.

9.3.3 Second Iteration: with Constraints

The second iteration of CALSIM used the DOC constraints developed from the base case organic carbon concentration at the urban intakes and the island volume – flow relationships from the first iteration fingerprinting results. CALSIM limited the releases from the project islands when the volume of water released from the islands and current DOC concentration on the islands was high enough that the additional DOC mass would violate the D-1643 Water Quality Management Plan (WQMP) organic carbon constraints.

These new CALSIM simulations included an additional operational strategy of circulation. The purpose behind this strategy was to dilute the high concentrations on the project islands by diverting water at the southern integrated facility on each island while releasing the same amount of water from the northern integrated facility. The net change in storage on the islands remained unchanged, but high DOC on the islands was reduced. A negative impact of this operation was that the DOC on the islands mixed with the low DOC water in the surrounding channels. The CALSIM DOC constraints still limited the amount of water released during a circulation operation in the same way that they limited regular project island releases.

HYDRO was then used to simulate flow and stage in the Delta based on the new CALSIM operations. The flow and stage results were then used in QUAL to simulate the EC and DOC at the three urban intakes used in the fingerprinting as well as water quality at CCWD's LVR intake.

The final results of the IDS study that made use of this methodology are described in DWR's *In-Delta Storage Program State Feasibility Study Draft Report on Water Quality* (2003).

9.4 Fingerprinting Results

As described in Section 9.3.2, each of the inflows into the Delta, including water entering the Delta from DSM2's ocean boundary at Martinez and the releases from the project islands, was assigned a unique conservative tracer constituent and then independently simulated in QUAL. This tracer constituent was arbitrarily assigned a value of 10,000 as recommended by Anderson (2002). The relative contribution of each source at the three urban intakes: RS, SWP, and CVP, was calculated by dividing the contribution from each source by the total contribution of all sources. Since DSM2 conserves mass, the combined concentration from all sources was equal to 10,000.[1]

Examples of selected volumetric fingerprinting results from the IDS study at RS are shown as pie charts (Figure 9.3). Although eight different sources were used in the QUAL simulation, the results were combined into four different sources: IDS project islands, San Joaquin River, Sacramento River, and other. Daily average results for the first day of each month are presented with the monthly average results.
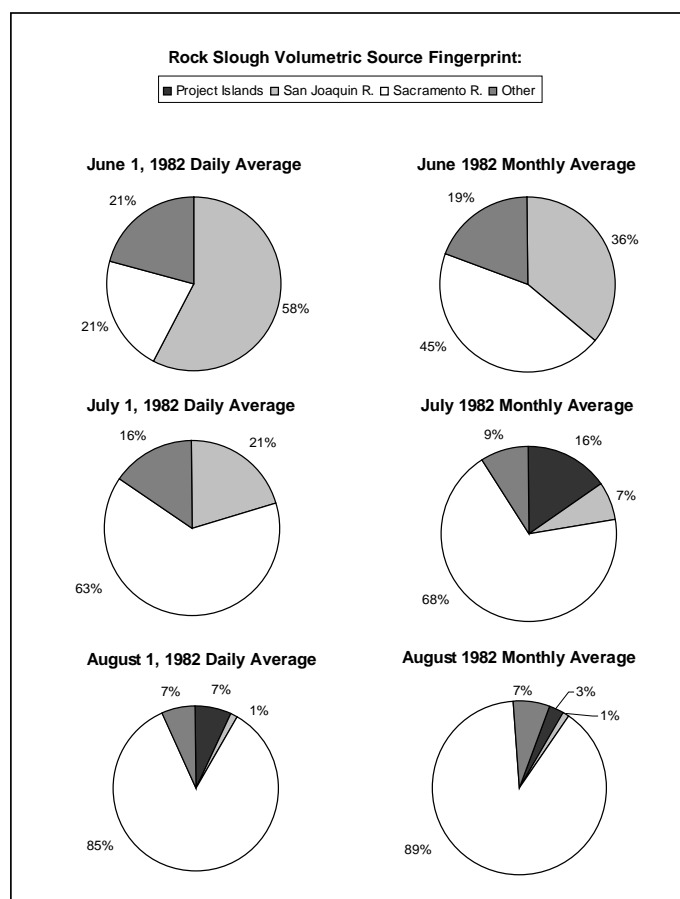
Figure 9.3: Selected Rock Slough Volumetric Fingerprint Pie Charts.

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[1] The assumption that DSM2 conserves mass can be verified by using a volume fingerprinting analysis. When a uniform concentration, say 10,000 mg/L, is assigned to every inflow, the sum of the source water concentrations at any point in the Delta will approach the uniform concentration assigned at each of the sources.

The relative contribution of source water at Rock Slough is highly variable by both day and month. For example, for July 1, 1982, Rock Slough source water was 63% from the Sacramento River, 21% from the San Joaquin, and 16% from other sources. None of the water on July 1, 1982 came from the project islands. But for the July 1982 monthly average, only 7% of the water at Rock Slough came from the San Joaquin and 16% of the water came from the IDS project islands. Though values after the release period on August 1, 1982 still showed 7% of the water at Rock Slough as having originated in the project islands, this was still less than the July monthly average of 16%. In this case, a single daily distribution was not a good tool for developing volume - flow relationships.

If only a few sources are being analyzed, area charts are also useful in illustrating the sensitivity of change in the relative contributions of different sources at a given location. Examples of area chart volumetric fingerprinting results for RS, SWP, and CVP from the IDS study are shown in Figures 9.4 – 9.6. In an area chart, instead of looking at a specific or an averaged period of arbitrary length, the relative contribution of each source is stacked in a time series with the other sources. The sum of all the contributions will equal 100%.

For the same July 1982 project island release, the percentage of project island water at Rock Slough quickly increased in July, but slowly trailed off in August through October (Figure 9.4). During the time that the percent of project island water decreased, the percentage of water from other sources remained relatively constant and the percentage of Sacramento River water increased. The area charts show similar trends in the July 1979, 1980, 1981 and 1986 project island releases.

Though the area charts do not provide quantitative relationships, they are easy to generate and are useful in illustrating the temporal response of a few parameters at the same time. A limitation in using area charts is that the plots become very difficult to interpret as the number of time series increases.

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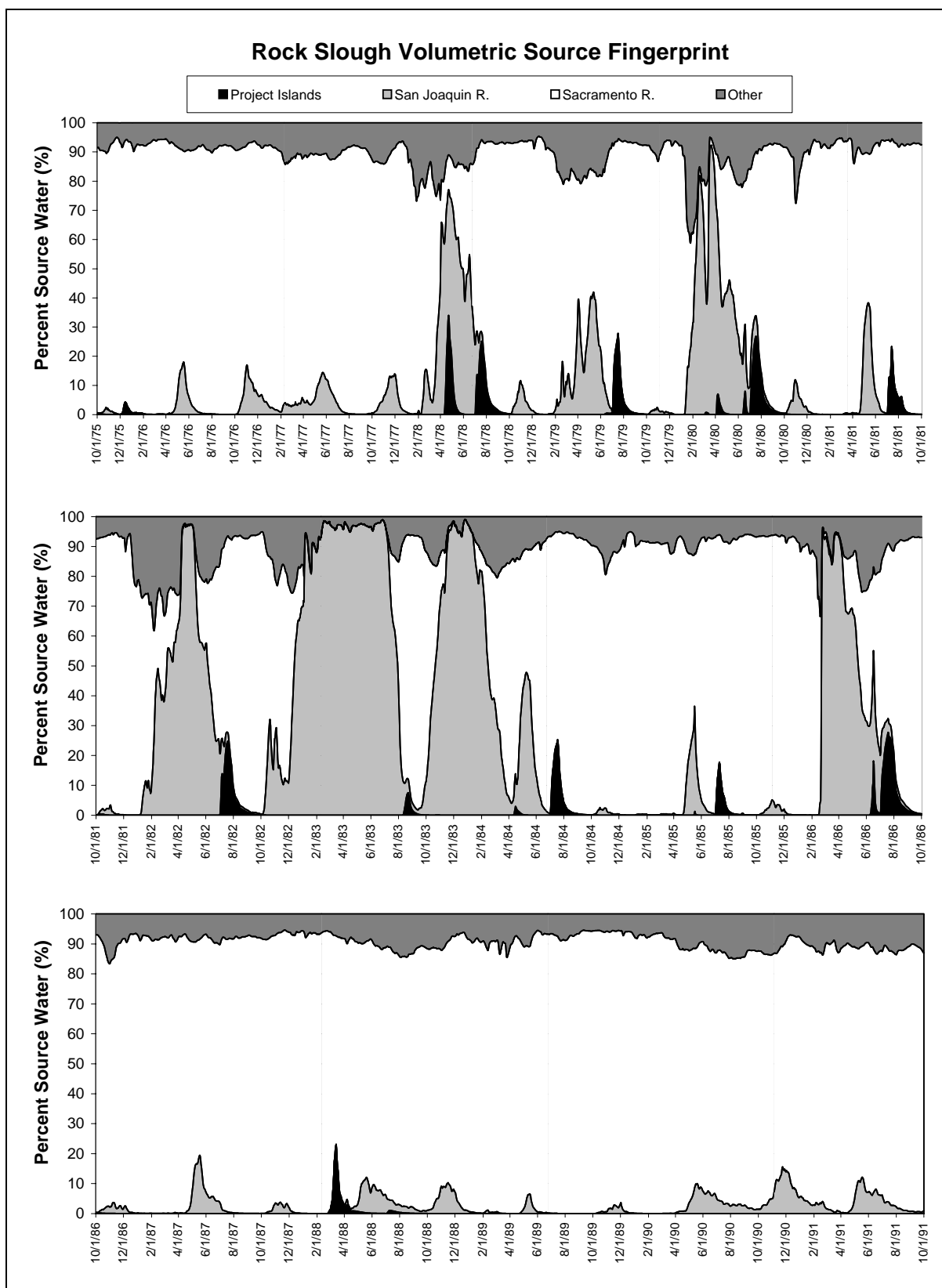
Figure 9.4: Rock Slough (RS) Volumetric Fingerprint Area Chart.
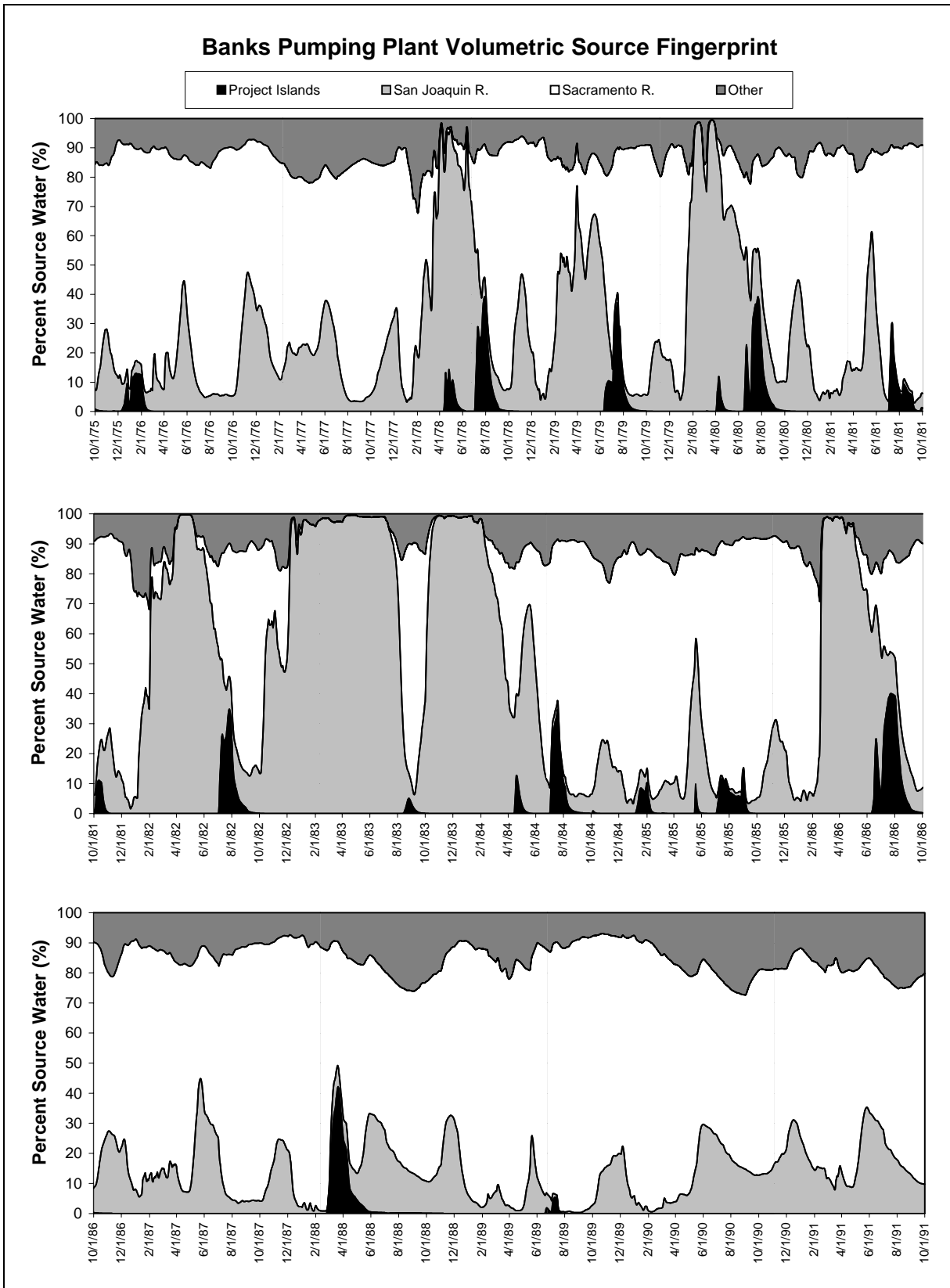
Figure 9.5: Banks Pumping Plant (SWP) Volumetric Fingerprint Area Chart.

Figure 9.6: Tracy Pumping Plant (CVP) Volumetric Fingerprint Area Chart.

9.5 Island Volume - Flow Relationships

Even though the volumetric fingerprint area charts are useful in illustrating the relative contribution of island water over time at each of the urban intake facilities, the area charts get busy quickly. Since CALSIM independently operated the two IDS project islands, it was necessary to develop separate island volume - flow relationships for each island at all three of the urban intakes. These relat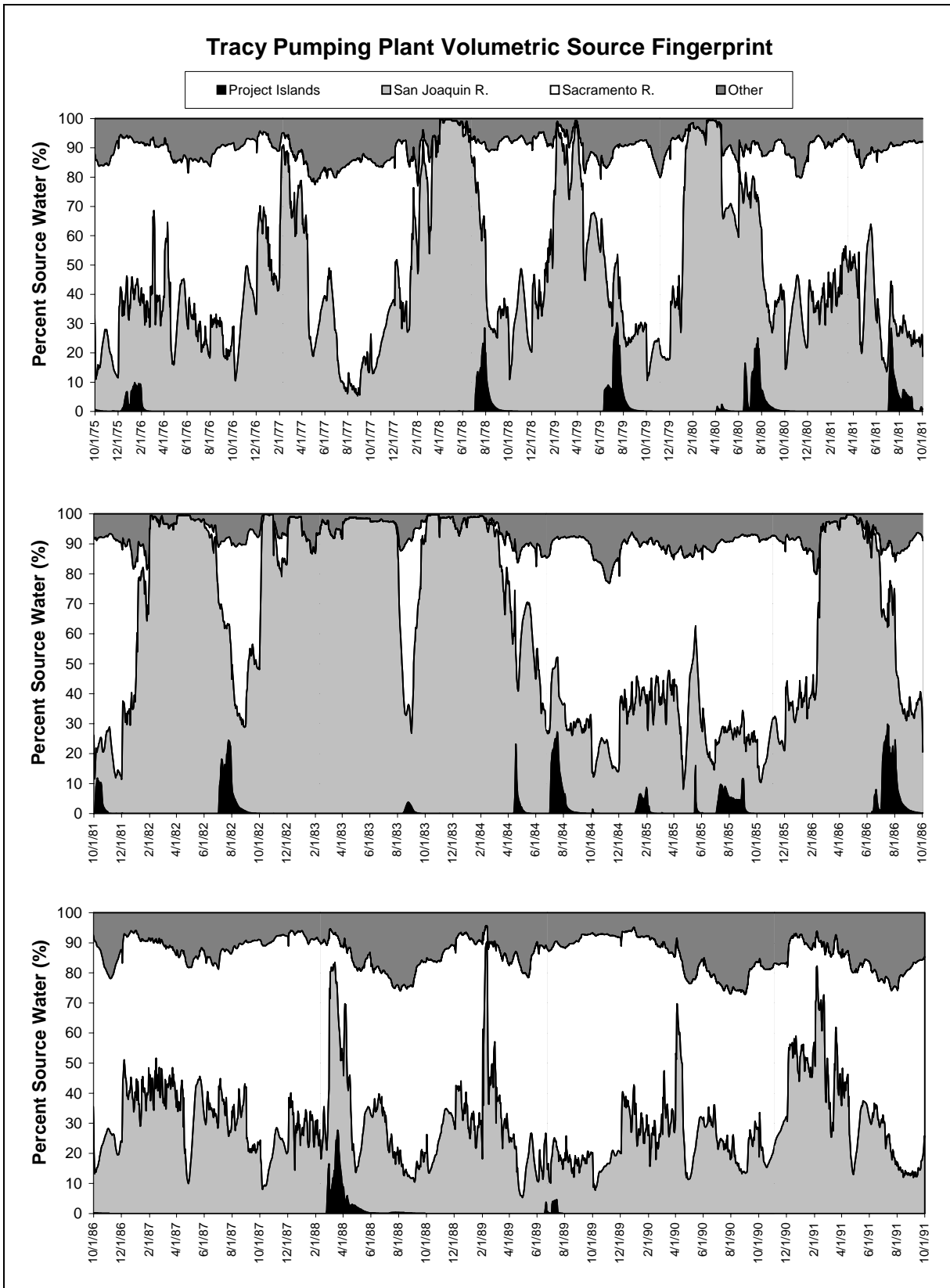ionships were developed by examining the response of island volume at the urban intakes to various flow parameters including:

- ❑ E/I ratio
- ❑ Island releases
- ❑ Sacramento River inflow
- ❑ San Joaquin River inflow
- ❑ Total Delta inflows
- ❑ Combined SWP and CVP exports
- ❑ Only SWP exports
- ❑ Only CVP exports
- ❑ Combined CCWD diversions

An example time series of the percent volume contribution of each of the project islands at Rock Slough along with the combined SWP and CVP exports and the San Joaquin River flow (Figure 9.7) illustrates the difficulty in finding a relationship between a single flow parameter and the percentage of island water reaching Rock Slough. Therefore, relationships based on multiple linear regressions were developed for the three urban intakes (Table 9.1).

The length of time that project release water remains in the Delta was important when developing DOC constraints in CALSIM. Water released at the beginning of a release period contributed new organic carbon to the urban intakes. Whereas water released towards the end of a release period or at the beginning of a release period shortly after previous release period needed to account for the accumulation of organic carbon from previous releases. With this in mind, running averages of the releases were used when developing the island volume - flow relationships.

Since this particular study was based on a future level of development, DSM2 assumed permanent South Delta barriers (see *DWR*, 2003 for more information on the configuration and timing of these barriers). No parameter for the operation of these barriers was directly incorporated into the island volume - flow relationships; however, the barriers were indirectly accounted for in the Rock Slough equation by developing four different equations: two from April through November in which the barriers might be operated, and two from December through March when the barriers were never operated. In the April through November equations, San Joaquin River flow was used as a surrogate to identify periods when the barriers would be inoperable due to high flows.

The equations were developed through a trial and error process using the R^2 statistic as a measure of fitness. The variables and range of values used in the equations listed in Table 9.1 are described in Table 9.2. Though a formal scale analysis was not conducted to simplify the equations in Table 9.1, each equation was quickly checked using numbers taken from Table 9.2

and found to yield reasonable results. Time constraints prevented re-entering the historical flow parameters into the equations and performing a statistical analysis on accuracy of the equations to forecast island volume relative to the modeled island volume.
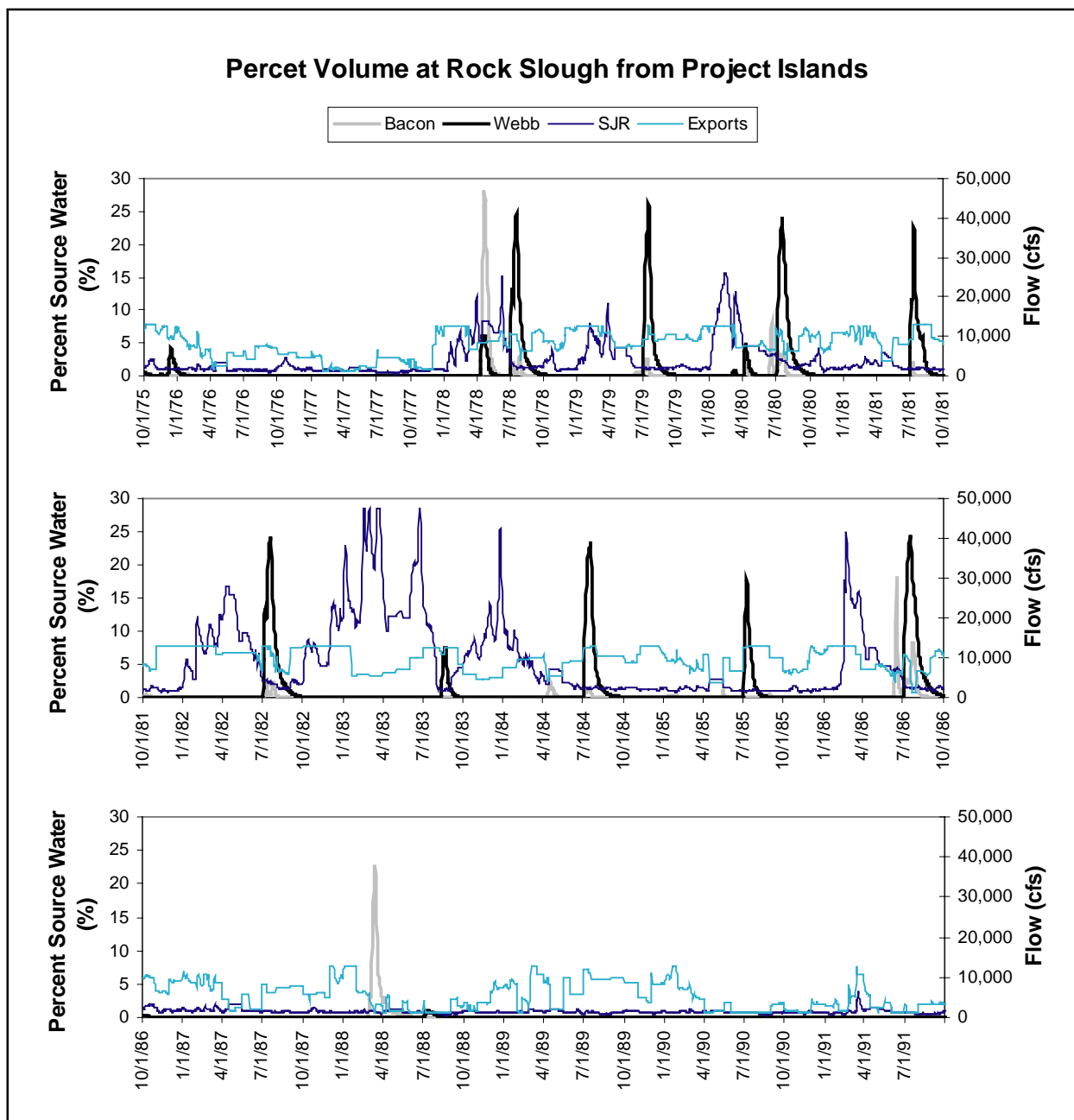
Figure 9.7: Percent Volume at Rock Slough from Project Islands.

Table 9.1: Percent Island Volume - Flow Relationships.

Urban Intake	Island	Relationship	R^2
RS	Bacon	**Apr. – Nov., $Q_{SJR} > 8,500$ cfs** $V = -1.93 \times 10^{-3} Q_{Sac} - 1.3 \times 10^{-3} Q_{SJR} + 1.2 \times 10^{-3} Q_{inflow} + 1.27 \times 10^{3} Q_{SWP+CVP}$ $- 4.4 \times 10^{2} E/I - 6.43 \times 10^{3} Q_{CCWD} + 1.02 \times 10^{-2} Q_{Bacon, 20-day\,ave} - 9.79 \times 10^{6}$	0.84
		Apr. – Nov., $Q_{SJR} \leq 8,500$ cfs $V = 0.05$	N/A
		Dec. – Mar., E/I ≤ 0.37 $V = 1.89 \times 10^{-2} Q_{Sac} + 2.49 \times 10^{-2} Q_{SJR} - 2.0 \times 10^{-3} Q_{inflow} - 5.58 \times 10^{-2} Q_{SWP+CVP}$ $+ 7.80 \times 10^{2} E/I - 1.0860 \times 10^{2} Q_{CCWD} + 1.43 \times 10^{-2} Q_{Bacon, 20-day\,ave} + 1.05 \times 10^{4}$	0.92
		Dec. – Mar., E/I > 0.37 $V = -1.16 \times 10^{-5} Q_{Sac} + 1.83 \times 10^{-5} Q_{SJR} + 4.71 \times 10^{-7} Q_{inflow} - 6.03 \times 10^{-6} Q_{SWP+CVP}$ $- 1.4 \times 10^{-1} E/I + 5.60 \times 10^{-4} Q_{CCWD} + 3.36 \times 10^{-4} Q_{Bacon, 20-day\,ave} + 1.6 \times 10^{-1}$	0.88
	Webb	$V = 8.8 \times 10^{-3} Q_{Webb, 20-day\,ave} + 8.5 \times 10^{-2}$	0.90
SWP	Bacon	$V = 2.56 \times 10^{-4} Q_{SWP+CVP} - 3.6 \times 10^{-4} Q_{SWP} + 1.9 \times 10^{-1} E/I$ $+ 5.2 \times 10^{-3} Q_{Webb, 20-day\,ave} - 3.69 \times 10^{-1}$	0.80
	Webb	$V = -6.54 \times 10^{-1} E/I + 1.13 \times 10^{-2} Q_{Bacon, 18-day\,ave} + 4.77 \times 10^{-1}$	0.70
CVP	Bacon	$V = 6.1 \times 10^{-3} Q_{Bacon, 8-day\,ave} + 1.67 \times 10^{-1}$	0.69
	Webb	$V = -5.2 x 10^{-05} Q_{SWP+CVP} + 2.01 \times 10^{-4} Q_{CVP} + 3.07 \times 10^{-1} E/I$ $+ 3.6 \times 10^{-3} Q_{Webb, 20-day\,ave} - 2.59 \times 10^{-1}$	0.79

Table 9.2: Sensitivity of Flow Parameters in Table 9.1.

Variable	*Flow Parameter*	*Range of Values*
E/I	Delta export / inflow ratio	0 – 1
Q_{CCWD}	Contra Costa WD diversions	0 – 600 cfs
$Q_{Bacon, 8-day}$	8-day average of Bacon Island releases	0 – 2,500 cfs
$Q_{Bacon, 20-day}$	20-day average of Bacon Island releases	0 – 2,500 cfs
$Q_{Webb, 20-day}$	20-day average of Webb Tract releases	0 – 2,500 cfs
Q_{SWP}	SWP exports	0 – 8,500 cfs
Q_{CVP}	CVP exports	0 – 5,000 cfs
$Q_{SWP+CVP}$	Combined SWP & CVP exports	1,500 – 13,000 cfs
Q_{SJR}	San Joaquin River flow	1,000 – 50,000 cfs
Q_{Sac}	Sacramento River flow	5,000 – 80,000 cfs
Q_{inflow}	Total Delta inflows	6,000 – 200,000 cfs

9.6 Discussion

Though the actual CALSIM constraints are not described here, the methodology used to develop DOC constraints using DSM2 in an iterative process was illustrated. The process involves several steps. First, CALSIM generates boundary conditions for DSM2. DSM2 is used to calculate the base organic carbon concentrations at Delta urban intakes (i.e. water quality compliance locations). A separate DSM2 simulation calculates the amount of water at the Delta urban intakes that came from the IDS project islands through a volumetric fingerprinting simulation. Finally, island volume - flow relationships from the second DSM2 simulation are combined with both the base organic carbon concentrations and the actual water quality constraints to back calculate the maximum additional loading (and hence volume of water released) from the IDS project islands.

Using CALSIM and DSM2 in an iterative process is based upon several assumptions:

❑ The island volume - flow relationships can be developed in such a way that they may be easily integrated into CALSIM's decision making process,

❑ The flow conditions and operations used to develop the island volume - flow relationships will be similar to the flow conditions and operations used in the final CALSIM simulation (i.e. that the CALSIM operations in the first and second iterations are similar), and

❑ The DOC concentrations associated with water coming from all other sources are not significantly altered by the operation of the project.

Using QUAL fingerprint simulations instead of PTM particle fate to estimate the percentage of volume at each of the urban intakes that came from the project islands addresses all of the limitations of the old PTM based approach, and allows for the development of daily island volume - flow relationship equations. By assuming that the concentration of water from all other sources is not significantly altered by the operation of the project and by using the island volume - flow relationship equations, it is straight forward for CALSIM to reduce the volume of water released from either project island in order to meet the WQMP DOC standard.

Since DSM2 planning studies currently use standardized organic carbon loading for all of the non-IDS flow inputs into the Delta (Suits, 2002), changes in the concentrations of the volume of water from the river and non-project island inflows would be due only to changes in the overall mixing patterns in the Delta. Given that the changes in Net Delta Outflow, SWP / CVP exports, Sacramento River, and San Joaquin River inflows were relatively small over the course of the DSM2 studies (DWR, 2003), the assumption that the concentration of water from all other sources at the intakes was not significantly altered and that the CALSIM volumetric based DOC constraints were valid seems reasonable. However, should this methodology be used in other DSM2 simulations in which the other flow inputs' organic carbon loadings vary with flow, it may be necessary to estimate the change in organic carbon loading at the urban intakes.

Due to project time constraints, instead of holding the basic operation rules of the IDS islands constant, a circulation operation that was not part of the first iteration operations was added in CALSIM's second iteration. Though the circulation operation represented a sufficiently

significant change in the flow conditions that were used to develop the island volume - flow relationships, it was assumed that over the course of the 16-year QUAL fingerprinting study that enough different flow and island operations were sampled in order to make reasonable relationships.

When developing the relationships, the operation of the fist protection barrier at Old River at the head of the San Joaquin River was indirectly accounted for by making several conditional regressions for Rock Slough. The operation of the three remaining South Delta permanent barriers was not accounted for in the relationships.

Not all of the water released from the project islands would reach an urban intake in a single day; therefore, in order to account for organic carbon released from the project islands into Delta channels but that did not immediately reach any of the urban intakes, a running average of the releases from each island was used in the regressions. Several different running averages were considered for each intake relationship. This approach was not extended to using running averages for the inflows or exports.

Overall, the use of fingerprinting to develop organic carbon constraints was an improvement over the PTM-based organic carbon constraints. Furthermore, the fingerprinting results themselves aided in answering other hydrodynamic related questions about the operation of the IDS project. Though this methodology was developed with DSM2 planning studies in mind, the idea of linking QUAL volumetric fingerprints with CALSIM operations may lead to developing other water quality constraints in operations models.

9.7 Future Directions

The above methodology was developed over the course of a few weeks in response to requests to improve the previous PTM-based organic carbon constraints used in CALSIM. Though the new methodology allows for more flexibility in developing relationships suitable for use in CALSIM, it can be refined if it is to be used again by considering the following:

❑ The basic operational rules in the first and second iterations should be kept the same with the hopes that the resulting flow conditions will be about the same.

❑ An additional iteration to refine the island volume - flow relationships can be added after the first iteration by running a fingerprinting simulation while using organic carbon constraints developed from the first iteration.

❑ A mass fingerprint simulation should be run in the final iteration in order to check the validity of the assumption that the organic carbon concentration from the non-project island sources is not significantly changed by the re-operation of the system.

❑ A scale analysis can be performed to reduce the regressions into a less complex form.

- ❑ The validity of the regressions can be checked by a full circle analysis, in which a final set of equations can be created using a simulation based on the equations actually used in the production run and then the two sets of equations will be compared.

- ❑ Flow weighted averages or some form of autoregressive moving average (ARMA) model can be used to relate the various flow parameters with the contribution of island volume at the urban intakes.

- ❑ The operation of the barriers can be incorporated into the equations, either as coefficients on other flow inputs or as a means to divide flow data into smaller samples.

9.8 References

Anderson, J. (2002). "Chapter 14: DSM2 Fingerprinting Methodology." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Office of State Water Project Planning. Sacramento, CA.

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Suits, B. (2002). "Chapter 7: Generating Monthly Dissolved Organic Carbon and UVA at DSM2 Boundaries." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Office of State Water Project Planning. Sacramento, CA.

9.9 Website

The *In-Delta Storage Program State Feasibility Study Draft Report on Water Quality*, which includes the results of this fingerprinting approach, can be found at:

http://calwater.ca.gov/Programs/Storage/InDeltaStorageReports_2003/InDeltaFeasibilityStudies_Jan2004.shtml

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 10:
Development of Tidal Analysis Routines

Author: Brad Tom

10 Development of Tidal Analysis Routines

10.1 Introduction

The DWR Tidal Analysis package was developed in Java and designed to be linked to VPlotter and RMA Tools (an RMA2 model output postprocessor developed by DWR). The package includes routines to calculate tidal datums and stage/current phasing. When used with RMA tools, the routines can be used to calculate tidal datums and stage/current phasing for every node in the RMA model grid. (NOTE: This tool currently is designed only for use with RMA2.) The result can be plotted as a contour plot (Figure 10.1) or as a profile plot (Figure 10.2) using RMA Plot.

A tidal datum is a vertical reference based on some phase of the tide. The National Oceanic and Atmospheric Administration (NOAA) has defined 11 principal tidal datums. This chapter describes the methodology that was developed to calculate tidal datums in the Sacramento-San Joaquin Delta and in the Suisun Marsh.

DWR-Suisun Marsh Planning will be using tidal datums to:

- ❑ Analyze new data collected with the NAVD88 datum to establish accurate vertical control in the Delta and Marsh, and

- ❑ Create tidal datum contours of RMA2 model output for model study comparison.

Stage / current phasing is a measure of the difference in phase between stage and flow. DWR Division of Environmental Services Suisun Marsh Planning Section will be using stage / current phasing results along with other parameters to evaluate the potential for tidal trapping and tidal pumping, which are two important mixing processes in the Bay-Delta System.[1,2]

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[1] Tidal trapping is a tidal dispersion mechanism caused by geometric features that change the timing of currents. Channels tend to have more "progressive" wave characteristics where stage and flow are nearly correlated. Shoals, dead end sloughs, and bays generate "standing" waves due to wave reflection. When these geometric features interact, there can be radical mixing.

[2] Tidal pumping is a non-tidal phenomena caused by asymmetries in the tidal currents. For example, in levee breaches, flow enters as a jet and leaves as potential or "sink" flow. In the net, the center of the breach flows in, the edges of the breach flow out.
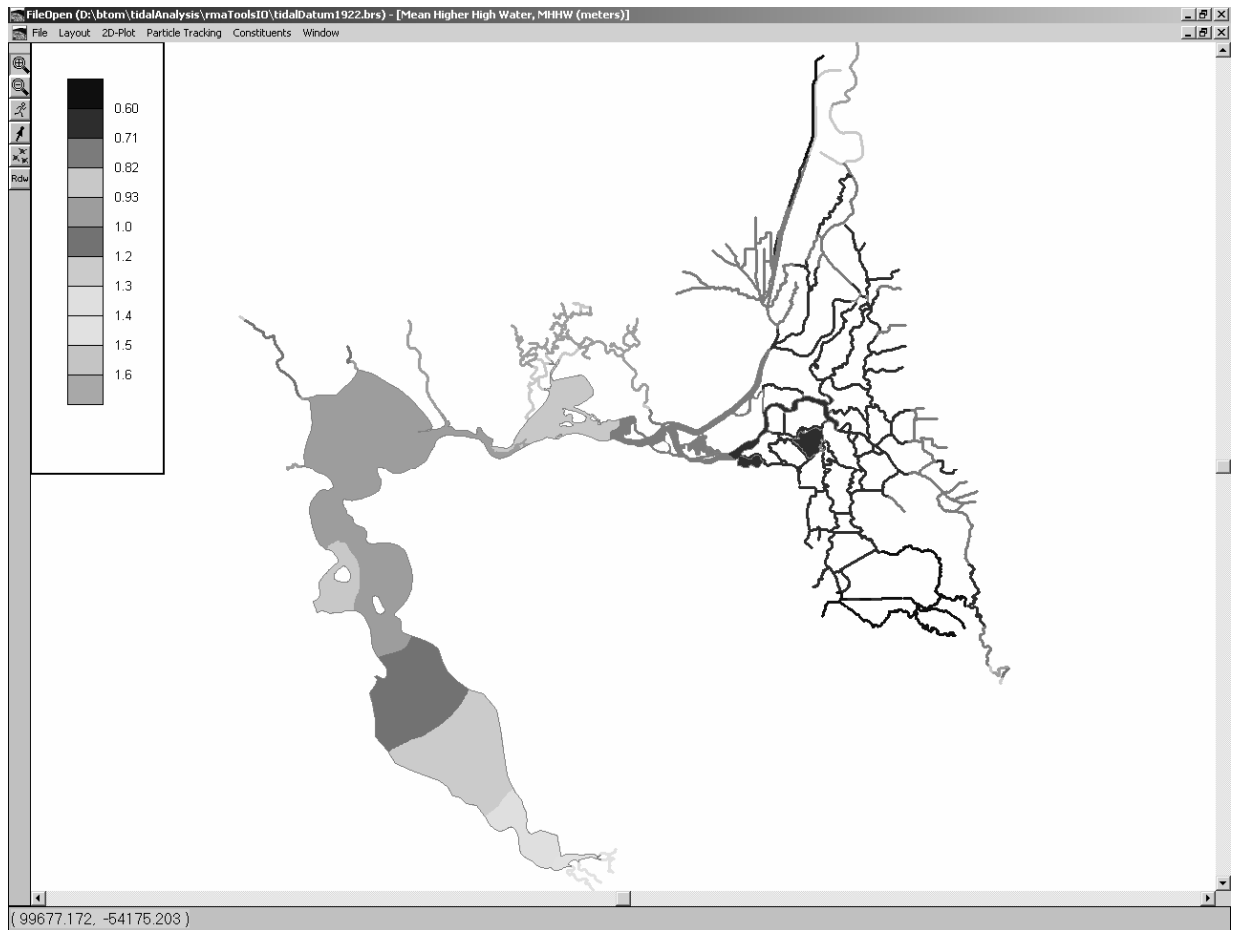
Figure 10.1: Contour Plot of MHHW (Mean Higher High Water) Using RMA2 Output.
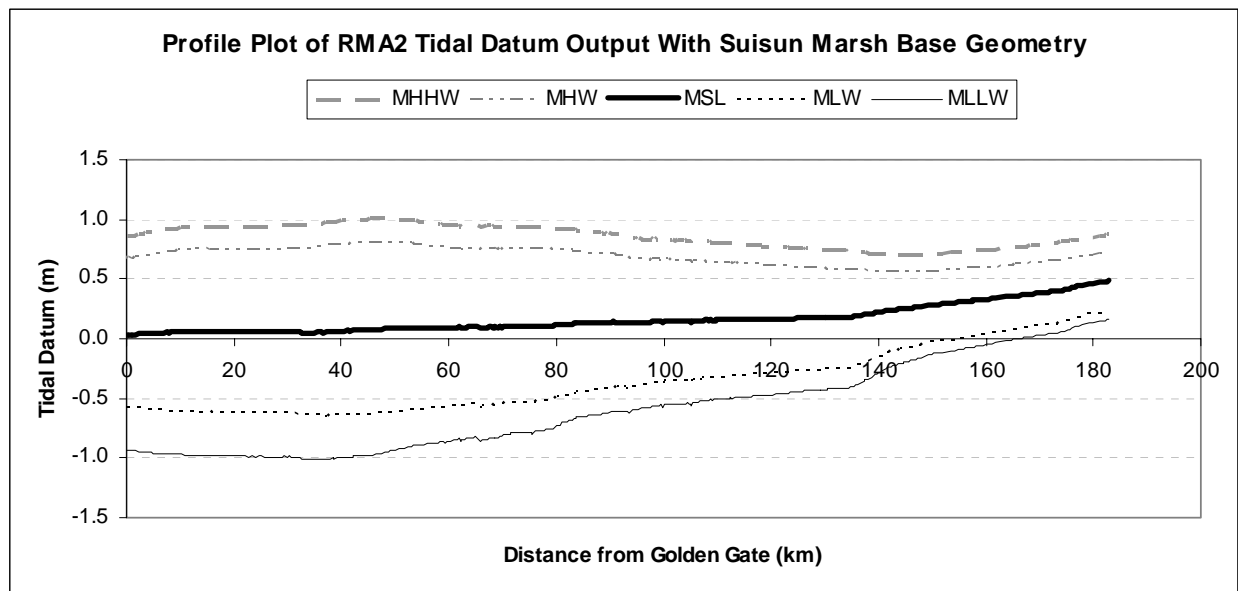
Figure 10.2: Tidal Datum Profile.

10.2 NOAA Computational Techniques

The principal tidal datums defined by NOAA are listed in Table 10.1. All of these tidal datums (with the exception of MSL) are calculated using averages of the high and/or low tide values for tidal day at a given location. A continuous time series of stage data is needed to calculate tidal datums. A tidal datum calculation routine must locate the high highs, low highs, low lows, and high lows. NOAA (2003) uses a computational scheme that involves:

1. Fitting a polynomial curve to a small portion of each peak / valley,
2. Finding the absolute maximum of each peak / absolute minimum of each valley, and
3. Using the peak maximums and valley minimums from Step 2 to calculate the tidal datum.

This method does not use real data values to calculate tidal datums, and is not adequate for calculating tidal datums in tidal estuaries like the Sacramento-San Joaquin Delta and Suisun Marsh.

**Table 10.1: Principal Tidal Datums Defined by NOAA.**

Tidal Datum	Abbreviation	Computation
Mean Higher High Water	MHHW	Average of all high highs
Mean High Water	MHW	Average of all highs
Mean Sea Level	MSL	Average of all values
Mean Low Water	MLW	Average of all lows
Mean Lower Low Water	MLLW	Average of all low lows
Mean Tide Level	MTL	Average of MHW and MLW
Diurnal Tidal Level	DTL	Average of MHHW and MLLW
Mean Range	Mn	MHW - MLW
Diurnal High Water Inequality	DHQ	MHHW - MHW
Diurnal Low Water Inequality	DLQ	MLW - MLLW
Great Diurnal Range	Gt	MHHW - MLLW

10.3 Sacramento / San Joaquin Delta and Suisun Marsh Data

Water levels in many areas of the Delta and Suisun Marsh are influenced by man-made structures, such as the Delta Cross Channel and the Clifton Court Forebay (CCF) gates. The operation of these structures changes the maximum and/or minimum stage values at nearby locations, which changes tidal datum values.

For example, when the CCF gates are opened at or near high tide, water levels in nearby locations drop suddenly (see Figure 10.3). This can change the shape of the curve in two ways. First, it can create a spike near or at the peak, which would change the shape of any curve fit. Second, it can reduce the maximum stage value. Although these man-made structures are not part of the natural system, they are permanent and will continue to influence tidal datum values in the foreseeable future.

For this reason, when working with observed data, real data is used to compute tidal datums. A high / low tide will be defined as the absolute maximum / minimum value in the vicinity of the peak / valley of the curve fit.
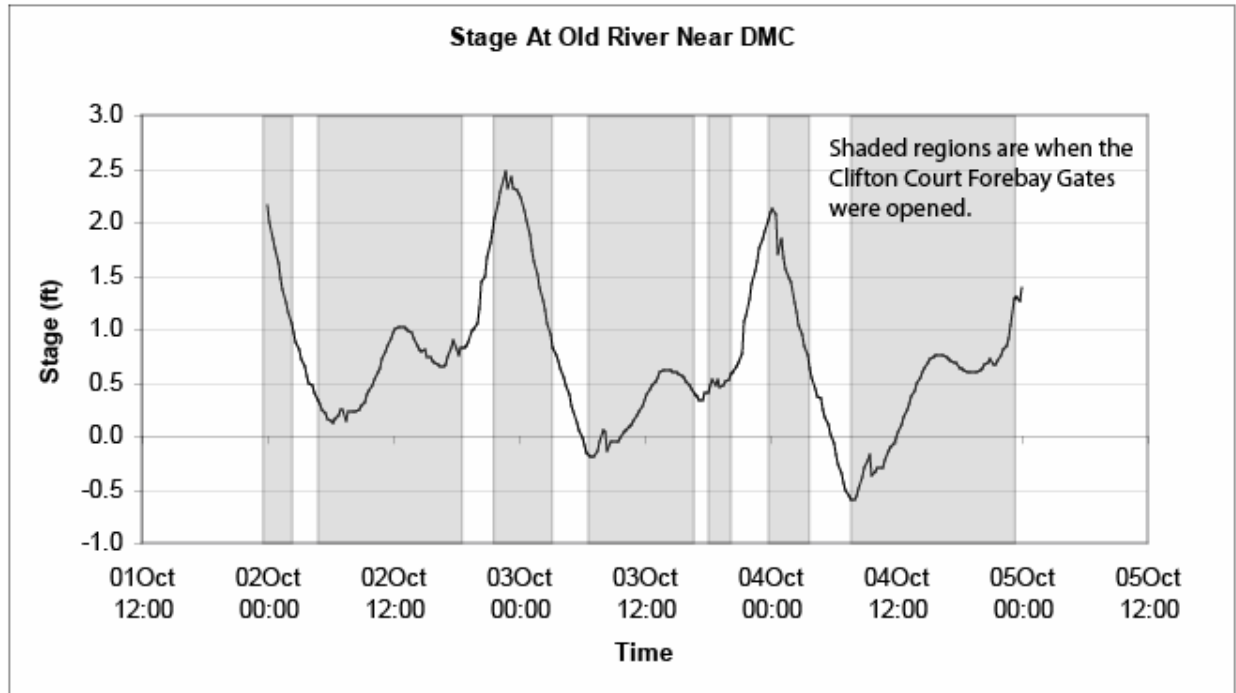
Figure 10.3: Stage at Old River near Delta Mendota Canal (ROLD047) in Oct. 1996.

10.4 DWR Tidal Analysis Package

The DWR Tidal Analysis package is written in Java and was designed to be linked to VPlotter and RMA Tools. The Tidal Analysis package contains a routine to calculate the principal tidal datums defined by NOAA, and a separate routine to calculate stage / current phasing.

10.4.1 Tidal Datum Routine

The tidal datum routine requires the following input:

❑ Continuous, regular time series stage data.

❑ *Backward and forward moving average length.* For stage data in the Delta and Suisun Marsh, three hours was found to be the best value.

❑ *Data search length.* This parameter is defined below. For stage data in the Delta and Suisun Marsh, three hours was found to be the best value.

The Tidal Analysis package uses the following algorithm (Figure 10.4) to calculate tidal datum:

1. Fit a curve to the stage data, using a six-hour centered moving average repeated 3 times. This new fitted curve will be used to identify the high and low tides. An example of a moving average based curve fitted to Old River near the Delta Mendota Canal (DMC) intakes is shown in Figure 10.5.

2. Create an irregular time series consisting of the local maximum values of the curve fit created in Step 1. Create another irregular time series for all the local minimum values.

3. Use the local maximum and minimum values of the curve fit to find the high and low tides in the stage data. For each local maximum value found in Step 2, find the absolute maximum stage value that is within the range specified by the *data search length* parameter. This is a high tide. For each local minimum value found in Step 2, find the absolute minimum stage value that is within the range specified by the data search length. This is a low tide. A three-hour data search length was used for all Delta and Suisun Marsh locations. Figure 10.6 shows the high and low tides calculated by using the curve fit local maximums and minimums.

4. Divide the high tides into higher high (HH) and lower high (LH) tides and the low tides into lower low (LL) and higher low (HL) tides. Go through the high tides two values at a time. The higher high (HH) tide is the larger of the two values, and lower high (LH) tide is the smaller or the two values. Repeat the procedure for the low tides; the lower low (LL) tide is the smaller of the two values, and the higher low (HL) tide is the smaller of the two values.

5. Calculate the rest of the NOAA tidal datum parameters using the computational scheme shown in Table 10.1.
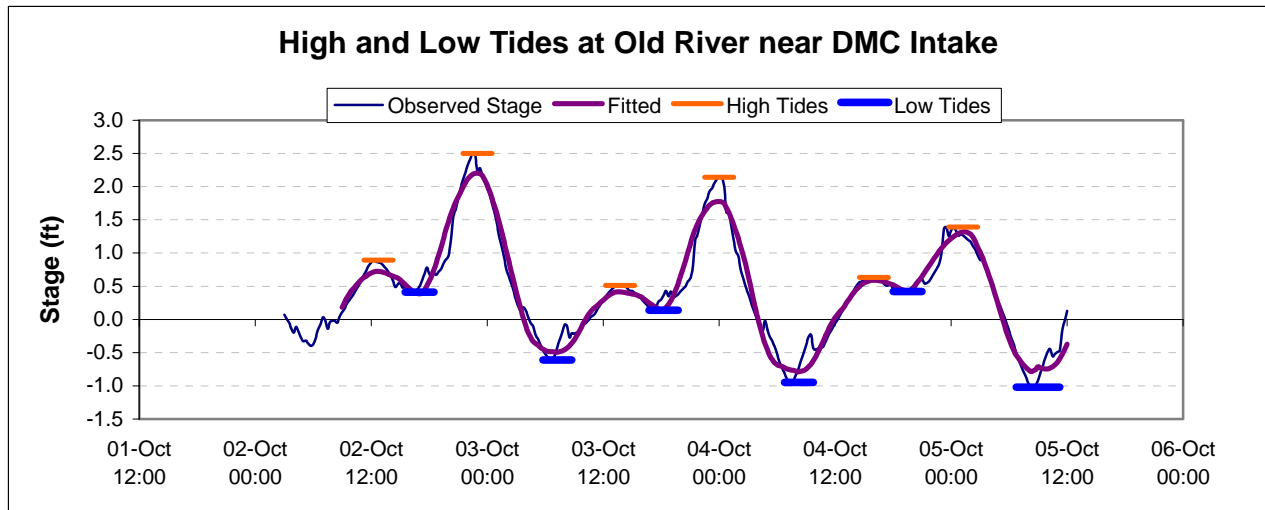
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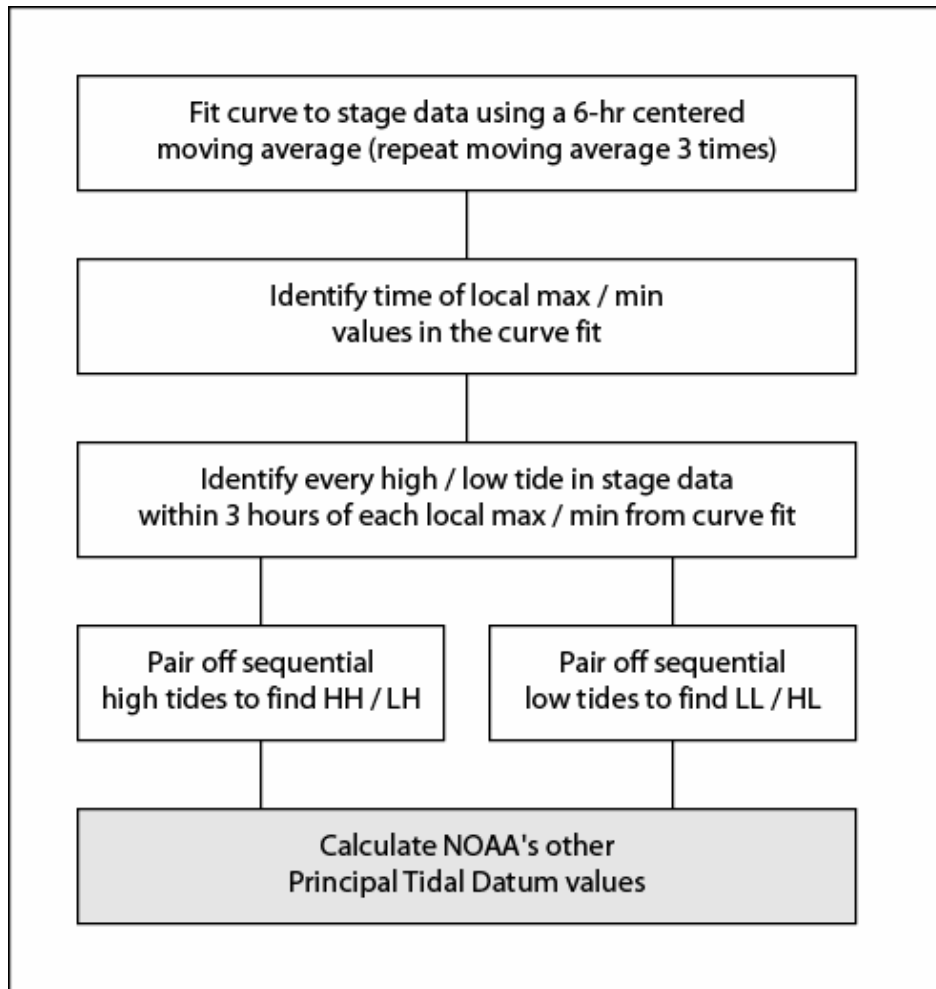
Figure 10.4: Tidal Datum Algorithm.
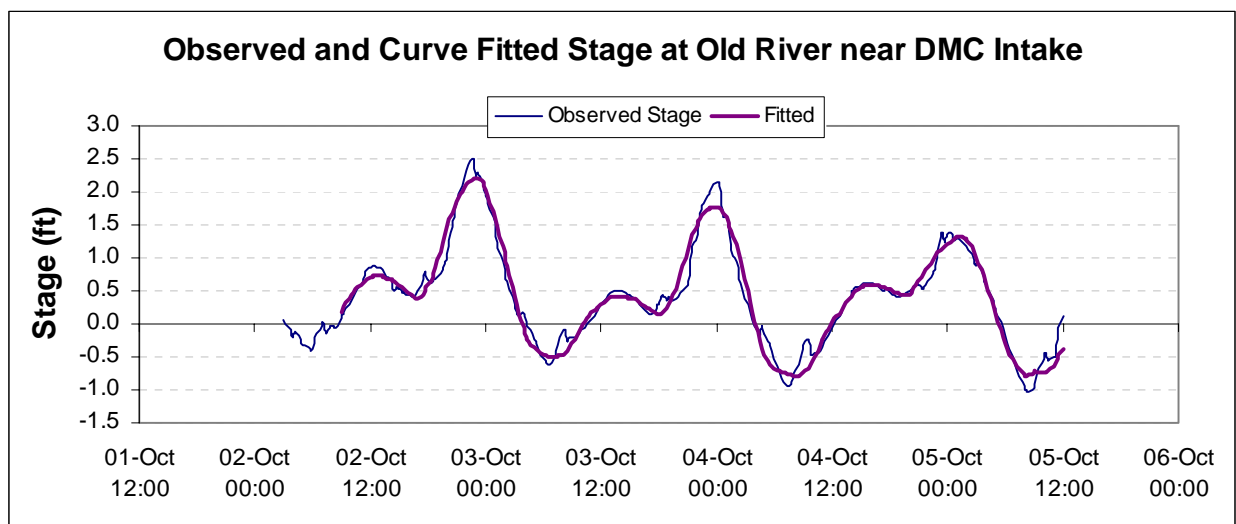
Figure 10.5: Curve Fitted to Observed Stage Data from Old River near the Delta Mendota Canal (DMC) Intake for Oct. 1996.

Figure 10.6: High and Low Tides Based on Curve Fitted Stage Data at Old River near the Delta Mendota Canal (DMC) Intake for Oct. 1996.

10.4.2   Stage / Current Phasing Routine

The Stage/Current Phasing routine requires the following input:

❑ Continuous, regular time series of stage data.

❑ Continuous, regular time series of flow data or velocity magnitude. The RMA2 model calculates x and y velocities instead of flow. The velocity magnitude is the square root of the sum of the squares of the x and y velocities.

❑ *Backward and forward moving average length*. For stage data in the Delta and Suisun Marsh, three hours was used.

❑ *Data search length*. This parameter is defined above (see Section 10.4.1). For stage data in the Delta and Suisun Marsh, three hours was used.

The algorithm used by the Tidal Analysis package to calculate NOAA's tidal datum parameters (see Section 10.4.1) was modified to also calculate the peak velocity magnitudes and then compare the timing of the velocity peaks with the high and low tides.

1. Fit a curve to the stage data, using a six-hour centered moving average repeated three times. This new fitted curve (Figure 10.5) will be used to identify the high and low tides.

2. Create an irregular time series consisting of the local maximum values of the curve fit created in Step 1. Create another irregular time series for all the local minimum values.

3. Use the local maximum and minimum values of the curve fit to find the high and low tides in the stage data. For each local maximum value found in Step 2, find the absolute

maximum stage value that is within the range specified by the *data search length* parameter. This is a high tide. For each local minimum value found in Step 2, find the absolute minimum stage value that is within the range specified by the data search length. This is a low tide. A three-hour data search length was used for all Delta and Suisun Marsh locations. Figure 10.6 shows the high and low tides calculated by using the curve fit local maximums and minimums.

4. Create an irregular time series consisting of all the local maximum velocity magnitudes. Since the velocity magnitude is based on the square root of the sum of the squares of the x and y (north-south and east-west) velocity components, it will always be a positive value.

5. Each velocity magnitude peak should have a corresponding stage peak (local max or min). Find the closest (in time) stage peak to each velocity peak, and calculate the time difference between the two. Average the values for the entire time series.
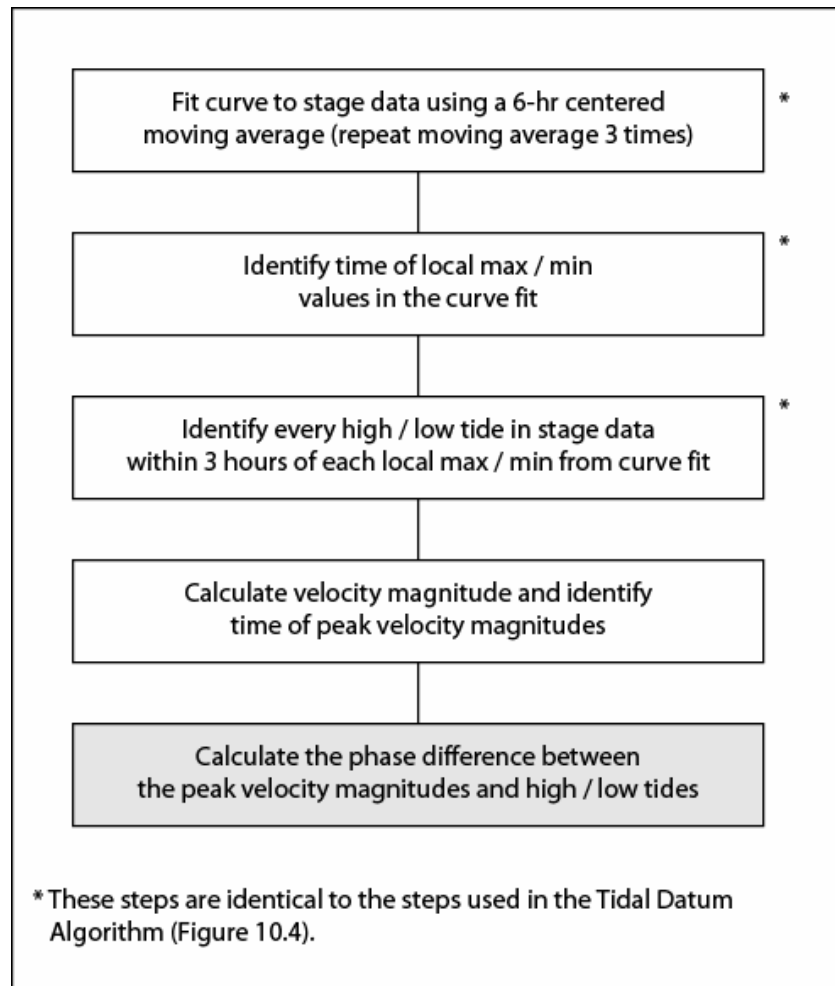
Figure 10.7: Stage / Current Phasing Algorithm.

10.5 Tidal Transitions

Tidal transitions can be difficult to analyze. Figure 10.8 is a plot of stage data and tidal analysis results on Old River near Delta Mendota Canal. The resulting high tide time series has an extra high tide in it, which could affect results.
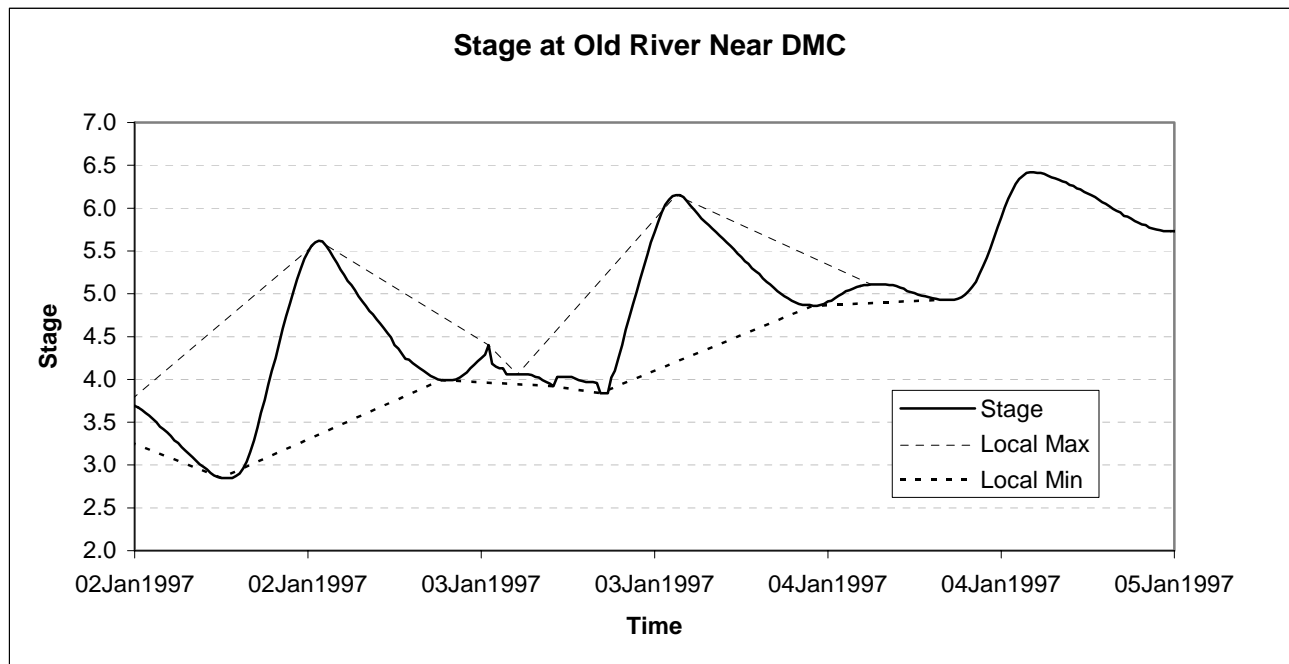
Figure 10.8: Example of Extra High and Low Tides Found in Stage Data During a Tidal Transition.

10.6 Future Directions

The Tidal Analysis package has not been thoroughly tested at the time of this writing. Tests planned for the summer of 2004 will use both observed data and RMA2 model output and include sensitivity analyses of the data search length parameter and a closer examination of how tidal transitions are being handled and their impact upon results.

10.7 Reference

National Oceanic and Atmospheric Administration. (2003). *Computational Techniques for Tidal Datums Handbook.*

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 11:
Website and DSM2 Users Group

Author: Min Yu

11 Website and DSM2 Users Group

11.1 Introduction

One of the objectives of the Delta Modeling Section Strategic Plan is to effectively disseminate information about the Section and its activities. The Section's outreach effort consists of two approaches:

❑ Utilizing the Section's website to provide information relating to the model development and model applications, while informing the public on work the Section has completed, and

❑ Forming a model users group to provide users with effective communication channels to interact, exchange ideas, and share information to make Delta Simulation Model II (DSM2) a better model.

11.2 Delta Modeling Section Website

The redesigned Section website,

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/index.cfm,

and other websites from the Bay-Delta Office were officially launched on January 7, 2004. The entire site (Figure 11.1) was completely reorganized and restructured, based on feedback and discussions at many months of meetings. As part of this standardization, the left navigation column shows different links to the various branches within the Bay-Delta Office, enabling users to more easily navigate the Bay-Delta Office web sites. A menu along the right column contains more frequently accessed pages specific to the Delta Modeling Section.

In addition to the main features including mission statement, program description, list of planning activities, projects and studies update, EIR/EIS, modeling tools, reports, and staff contact information, the website in particular has a 'Recent News' page for projects updates and workshop announcements. The goal of the website is to be more than simply an area of general information for activities in the office; rather, it is to provide a valuable resource for the modeling community and also to increase the frequency of visits from the public.

Figure 11.1: Screenshot of the Delta Modeling Section Website.

11.3 DSM2 Users Group

DSM2 has been widely used for three types of Delta simulations, namely historic conditions, forecasting future and real-time conditions, and planning studies. The number of users has increased since DSM2 was first introduced in 1997. Users now include staff from various consulting firms, federal agencies, and state agencies with a wider range of needs. During the past year and half, the number of users wanting to replicate the studies done by our Section as well as start their own studies has increased. In addition to questions concerning DSM2 use, users have been providing feedback on ways to improve DSM2.

To meet the above needs, a DSM2 Users Group was formed. It was also the Section's belief that the initiation of such a group would further reflect our renewed commitment to make the modeling tools and methods more transparent and available to the public. The main objectives of the DSM2 Users Group are to:

❑ Have direct interaction to better understand users' wishes and needs,

❑ Share information on studies done by DWR, other agencies or consultants, and

❑ Seek user contributions to DSM2 enhancement and development.

To achieve these objectives, the following website (Figure 11.2) was developed for the Users Group:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/dsm2usersgroup.cfm

Work plan, meeting announcements and materials, and contact information are available for download. The website also includes a bulletin board (Figure 11.3):

http://modeling.water.ca.gov/forum/index.php

where questions and answers from all DSM2 users are posted and archived, in order to establish better sharing of DSM2 Frequently Asked Questions (FAQ)s.

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Figure 11.2: Screenshot of the DSM2 Users Group Website.

Figure 11.3: Screenshot of the DSM2 Users Group Online Bulletin Board.

The first meeting was held on January 27, 2004. Participants included staff from consulting firms, such as CH2M Hill and Jones & Stokes, and agencies including Contra Costa Water District, USBR, and DWR. The highlights of the first meeting consisted of a brief review of the studies done by DWR using DSM2, and a presentation on the DSM2 database development. Furthermore, issues involving the use of the model and expectations on the users group were discussed. Participants agreed to meet quarterly.

11.4 Future Directions

The main purpose of the outreach plan is to serve the users of DSM2. This will be achieved by maintaining the website on a regular basis and strengthening the involvement from the DSM2 Users Group participants. In future DSM2 Users Group meetings, issues will be addressed by promoting continuous public dialogs between users. Presentations from Delta Modeling Section staff and other DSM2 users and Users Group bulletin board discussions will be saved for reference and use by future DSM2 users.

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Chapter 12:
Calculating Clifton Court Forebay Inflow

Author: Kate Le

12 Calculating Clifton Court Forebay Inflow

12.1 Introduction

Located in the southern portion of the Sacramento-San Joaquin Delta and about 20 miles southwest of the city of Stockton, Clifton Court Forebay is a regulated reservoir at the head of the State Water Project's (SWP) California Aqueduct. Flow into the forebay is controlled by five radial gates. Flow through the individual gates is not directly measured. DWR's Delta Field Division (DFD) indirectly measures inflow by calculating the difference in expected storage from the actual measured storage in the forebay.

Another method of calculating inflow is to use stage data measured both inside and outside of the forebay gates and gate heights. In 1988 a series of regressions were developed to determine the flow through the gates using the gate heights instead. This chapter describes the methodology used to develop these equations and then compares these equations with the DFD storage based estimates.

12.2 Field Tidal Gate Operations

The intake structure to Clifton Court is comprised of five 20' x 20' radial gates along Old River. Figure 12.1 shows the location and configuration of the gates in the field. These gates are generally operated during the tidal cycle to reduce approach velocities, prevent scour in adjacent channels, and minimize water level fluctuation in the south Delta. When a large head differential exists between the outside and the inside of the gates, instantaneous flows into the forebay could theoretically reach 15,000 cfs. However, existing operating procedures identify a maximum design rate of 12,000 cfs, which prevent water velocities in surrounding Delta channels from exceeding three feet per second (ft/s) to control erosion and prevent damage to the facility.

Generally, all five gates are operated to open and close in tandem. However, during maintenance and/or gate repairs, individual gate(s) may be independently operated. The daily opening and closing of gates depends on the scheduled SWP exports, timing and amplitude of the local tides, and storage availability in the forebay.

Gate operations are constrained by a scouring limit (i..e. 12,000 cfs) at the gates and water level concerns in the south Delta for local agricultural irrigators. An interim agreement between DWR and South Delta Water Agency, outlined in the Draft Agreement "Regarding Implementation of CALFED Bay Delta Program Activities in the Delta", specifies a series of priorities that dictate gate restrictions. The least restrictive operation is commonly referred to as Priority 3.

View of the intake gates from the outside the forebay (looking west).
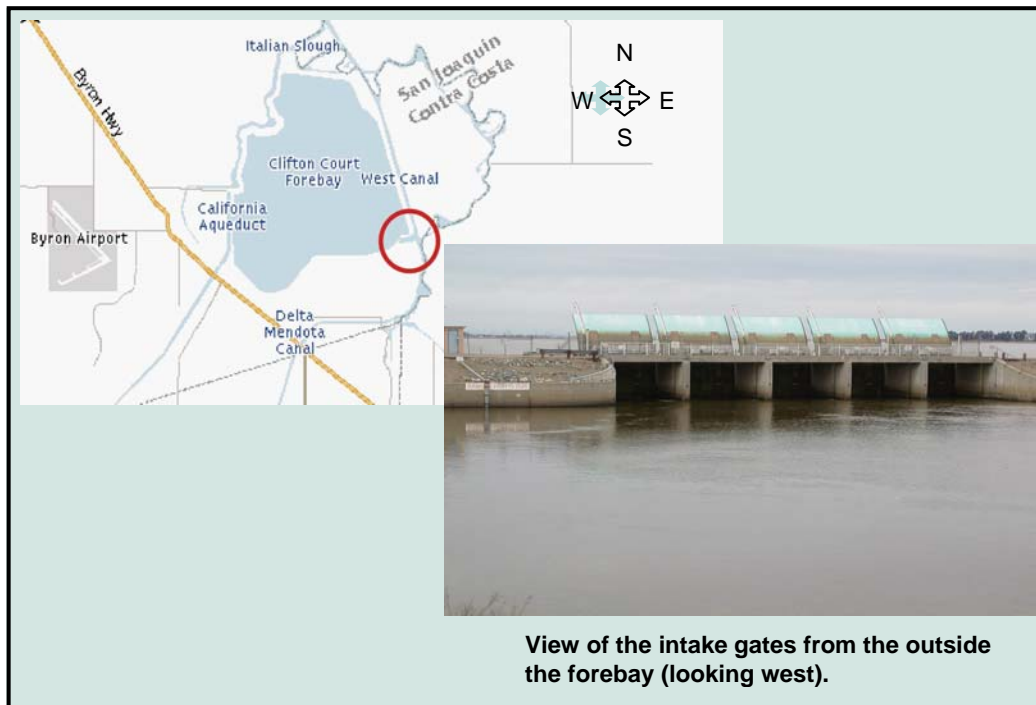
Figure 12.1: Location of Clifton Court Forebay Intake Gates.

DFD receives daily allocation information from the Project Operations Center, and knows when the gates can be opened based on forecast tides in the south Delta and at the forebay gates. If the water level inside the forebay is lower than outside, then DFD opens the gates for the time period allowed under the acceptable priority level at the time. When the water level inside is higher than outside or the gates cannot be opened under the current priority system, then the gates remain closed.

Once the allocation has been reached for the day, the gates are closed. If the allocation was not achieved for the day, then Joint Operations Center staff will adjust the schedule the same day to make up the remaining allocation the next day. The schedule for pumping at Banks must frequently be adjusted to accommodate the tide-based restrictions and still obtain the targeted allotment. The same is also the case when maintenance or debris limits the function of the Skinner Fish Facility or Banks Pumping Plant.

In general, DFD operates to Priority 3. However, due to low water levels or other constraints, Priority 2 or Priority 1 operation might be necessary to meet water allocation schedule for the day. An example of all three priorities is shown in Figure 12.2. The rules used to determine when the gates can be opened depend on whether the lower low tide is followed by the lower high or higher high tide.

The first situation is when the lower low tide is followed by the lower high tide. During this condition, Priority 3 allows the gates to open 1 hour after the lower low tide, close 2 hours after the higher low tide, open again 1 hour before the higher high tide, and close 2 hours before the

next lower low tide. Under Priority 2, the gates are allowed to open 1 hour after the lower low tide until 1 hour before higher low tide, and open again 1 hour before the higher high tide until 2 hours before the next lower low tide. Under Priority 1, the gates may be opened 1 hour after the lower high tide until 1 hour before the higher low tide and 1 hour after the higher high tide until 2 hours before the next lower low tide.
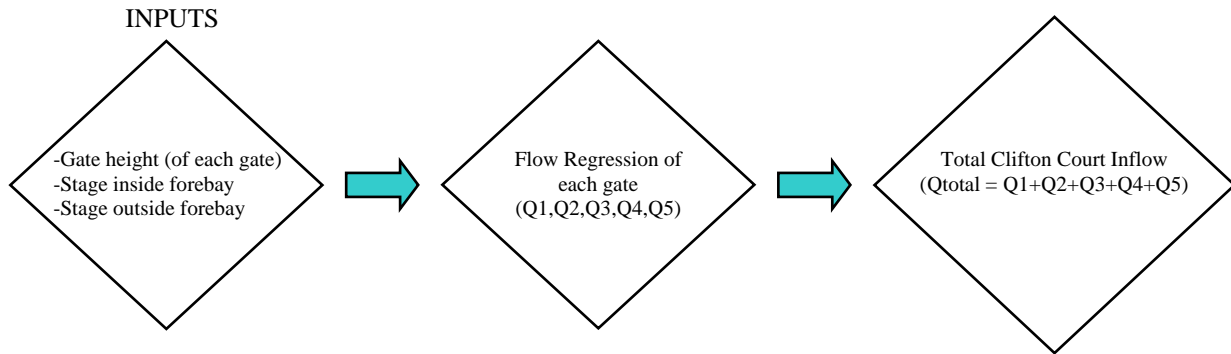
The second situation is after the tides have reversed, i.e. when the lower low tide is followed by the higher high tide. During this condition, Priority 3 allows the gates to open 1 hour before the higher high tide and remain open until 2 hours before the next lower low tide. Under Priority 2, the gates are allowed to open 1 hour before the higher high tide until 1 hour before the higher low tide and can reopen again 1 hour after the higher low tide until 2 hours before the next lower low tide. Under Priority 1, the gates may be opened 1 hour after the higher high tide until 1 hour before the higher low tide and 1 hour after the lower high tide until 2 hours before the next lower low tide. Essentially the Priority 1 operation is the same after the tides have reversed.
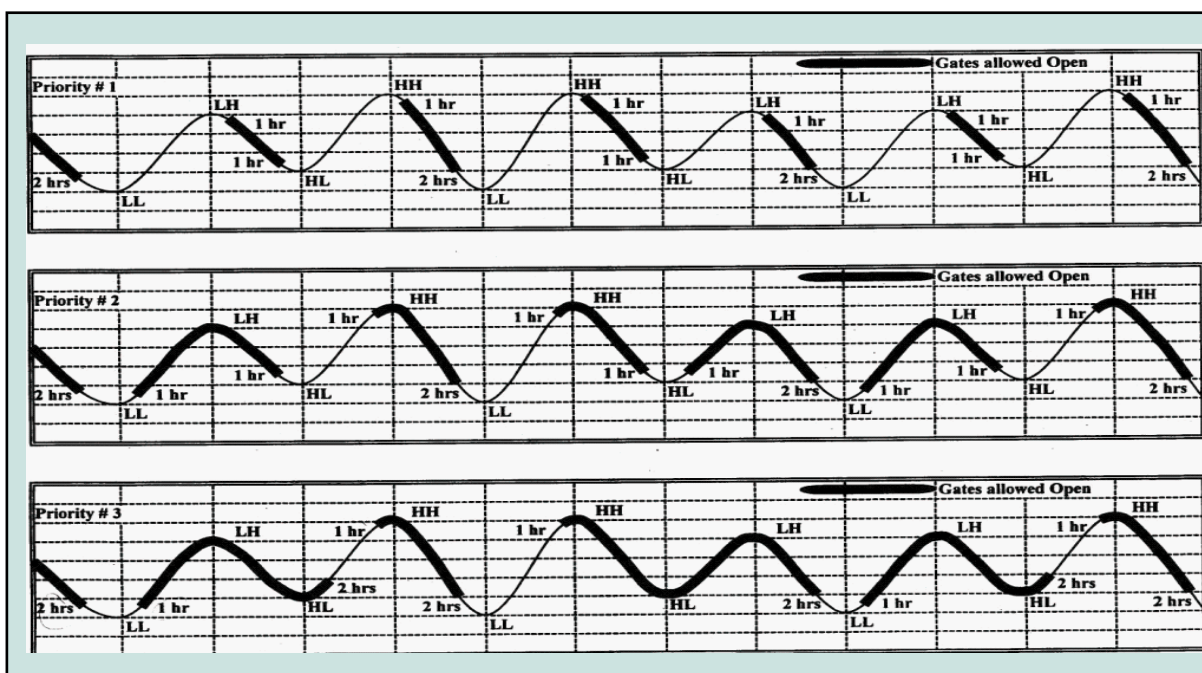
Figure 12.2: Clifton Court Forebay Gate Priority Operation Rules.

12.3 New Clifton Court Gate Equations

Hills (1988) developed a new set of gate position - elevation difference regressions to estimate the flow passing through the Clifton Court Forebay Gates. A flow chart illustrating Hills's methodology is shown below:

INPUTS

-Gate height (of each gate)
-Stage inside forebay
-Stage outside forebay

Flow Regression of
each gate
(Q1,Q2,Q3,Q4,Q5)

Total Clifton Court Inflow
(Qtotal = Q1+Q2+Q3+Q4+Q5)

Hills used data on the gate height (position), the difference in stage inside and outside of the forebay, and measured flow through each of the gates, i, to develop the following equations:

$$Q_1 = H_1 \left\{ 0.44 + 215.224 \left(Elev_{outside} - Elev_{inside} \right)^{\frac{1}{2}} \right\} \qquad \text{[Eqn. 12.1]}$$

$$Q_2 = H_2 \left\{ 4.46 + 181.804 \left(Elev_{outside} - Elev_{inside} \right)^{\frac{1}{2}} \right\} \qquad \text{[Eqn. 12.2]}$$

$$Q_3 = H_3 \left\{ 4.76 + 173.378 \left(Elev_{outside} - Elev_{inside} \right)^{\frac{1}{2}} \right\} \qquad \text{[Eqn. 12.3]}$$

$$Q_4 = H_4 \left\{ 3.380 + 173.378 \left(Elev_{outside} - Elev_{inside} \right)^{\frac{1}{2}} \right\} \qquad \text{[Eqn. 12.4]}$$

$$Q_5 = H_5 \left\{ 2.38 + 168.790 \left(Elev_{outside} - Elev_{inside} \right)^{\frac{1}{2}} \right\} \qquad \text{[Eqn. 12.5]}$$

$$Q_{total} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 \qquad \text{[Eqn. 12.6]}$$

where,

Q_i = flow through gate i (cfs),
H_i = gate height / position of gate i (ft),
$Elev_{outside}$ = stage outside Clifton Court Forebay (ft),
$Elev_{inside}$ = stage inside Clifton Court Forebay (ft), and
Q_{total} = Total Clifton Court gates inflow (cfs).

In 1997, DWR, SWP, Joint Operations Control staff used MS Excel to quickly and easily create estimates of Clifton Court inflows based on the gate heights and difference in stage inside and outside of the forebay.

12.4 Validation of the Equations

The DFD indirectly measures the net flow through the Clifton Court Forebay Gates by measuring the water levels in the forebay and estimating the anticipated change in storage due to pumping. These indirect measurements are then stored every 10 minutes on a DFD Information and Storage Retrieval (ISR) system which can be accessed only by the Department. Hills's equations were validated for August 2003 through September 2003 by comparing the total flow calculated using Equation 12.6 with the ISR measurements.

Both the DFD measured flow through the gates and the flow calculated using Hill's equations for August and September 2003 are shown in Figures 12.3 and 12.4. The difference between the DFD measured and calculated flows are compared with the Banks export levels for August and September 2003 in Figures 12.5 and 12.6. The plotted difference in flows includes times when all five gates were closed. Banks pumping was included in order to determine if any differences in the calculated and measured inflows could be attributed to different pumping conditions (i.e. low versus high pumping). The difference in flows is also compared with the stage outside and inside the Clifton Court Forebay for August and September 2003 in Figures 12.7 and 12.8.

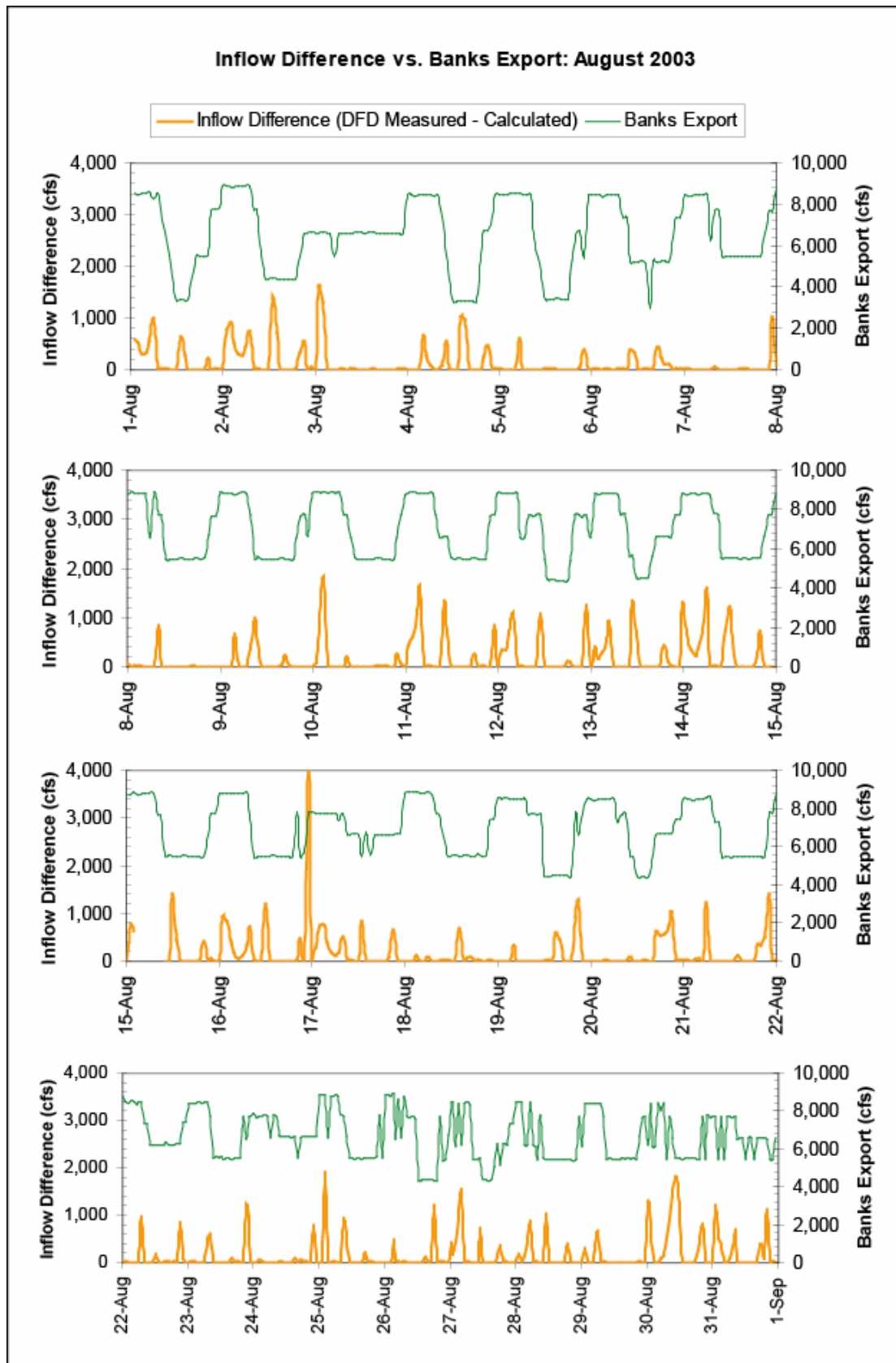This space intentionally left blank.
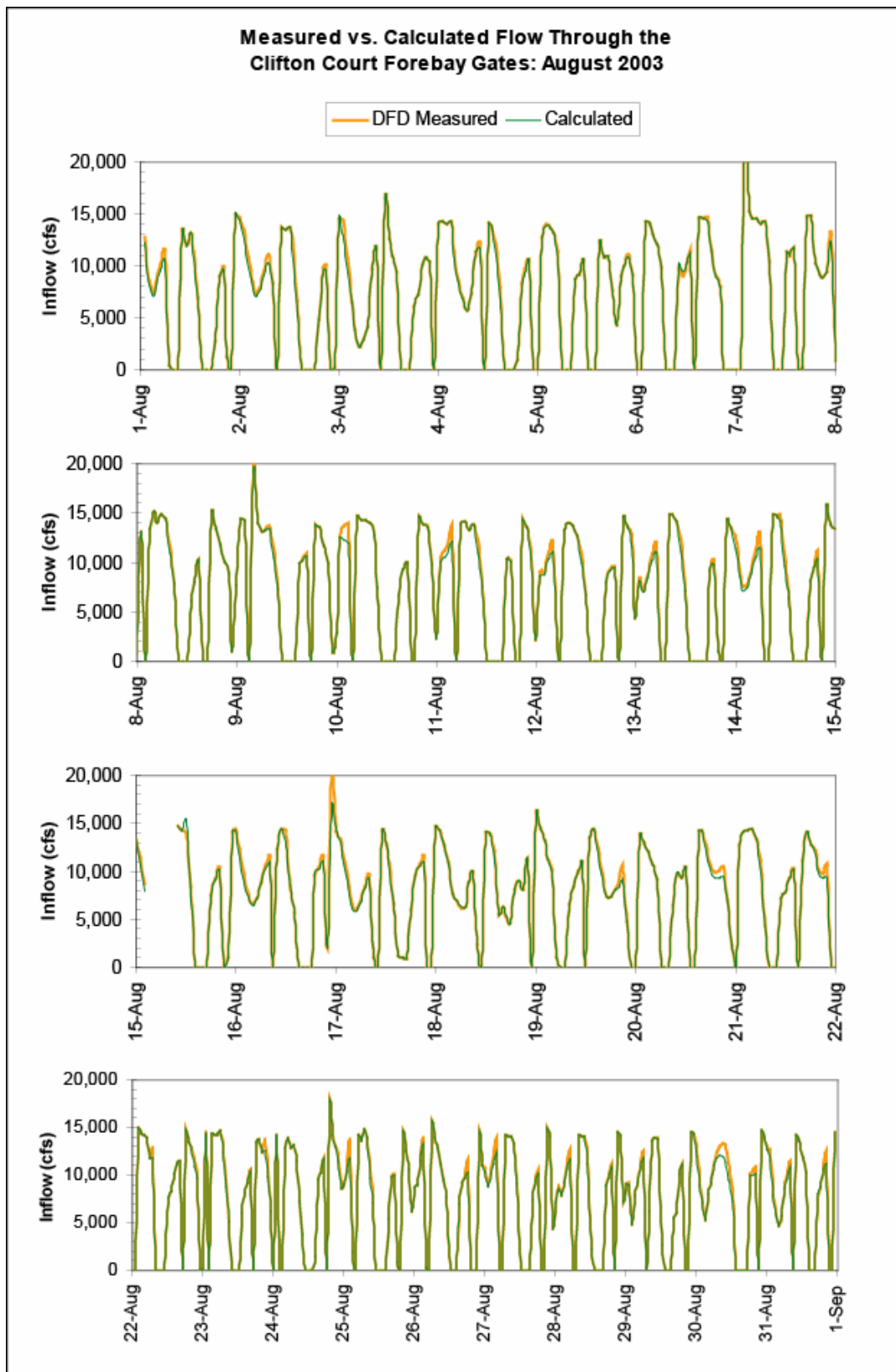
Figure 12.3: Measured vs. Calculated Flow Through the Clifton Court Forebay: August 2003.

12-6
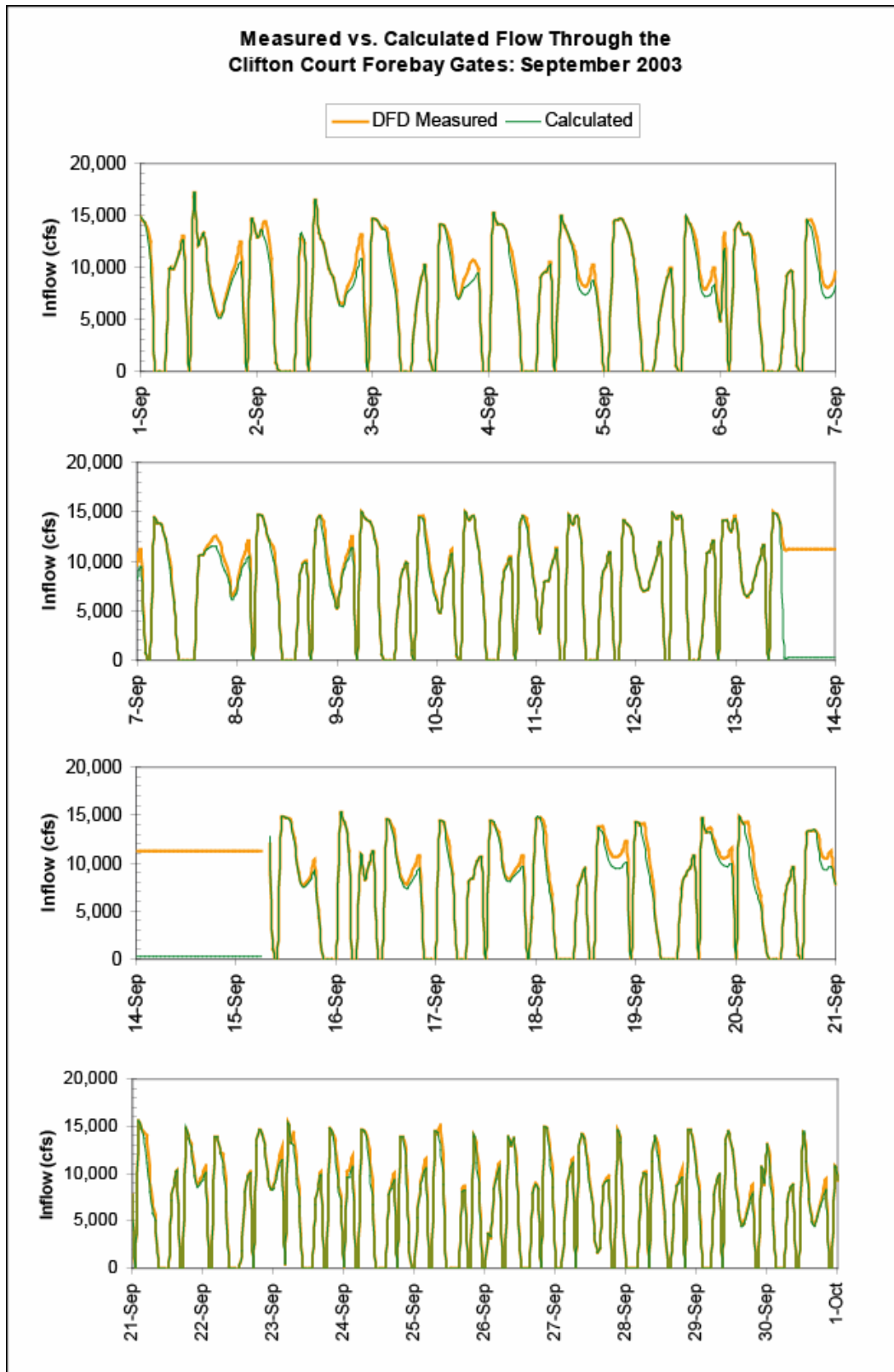
Figure 12.4: Measured vs. Calculated Flow Through the Clifton Court Forebay: September 2003.
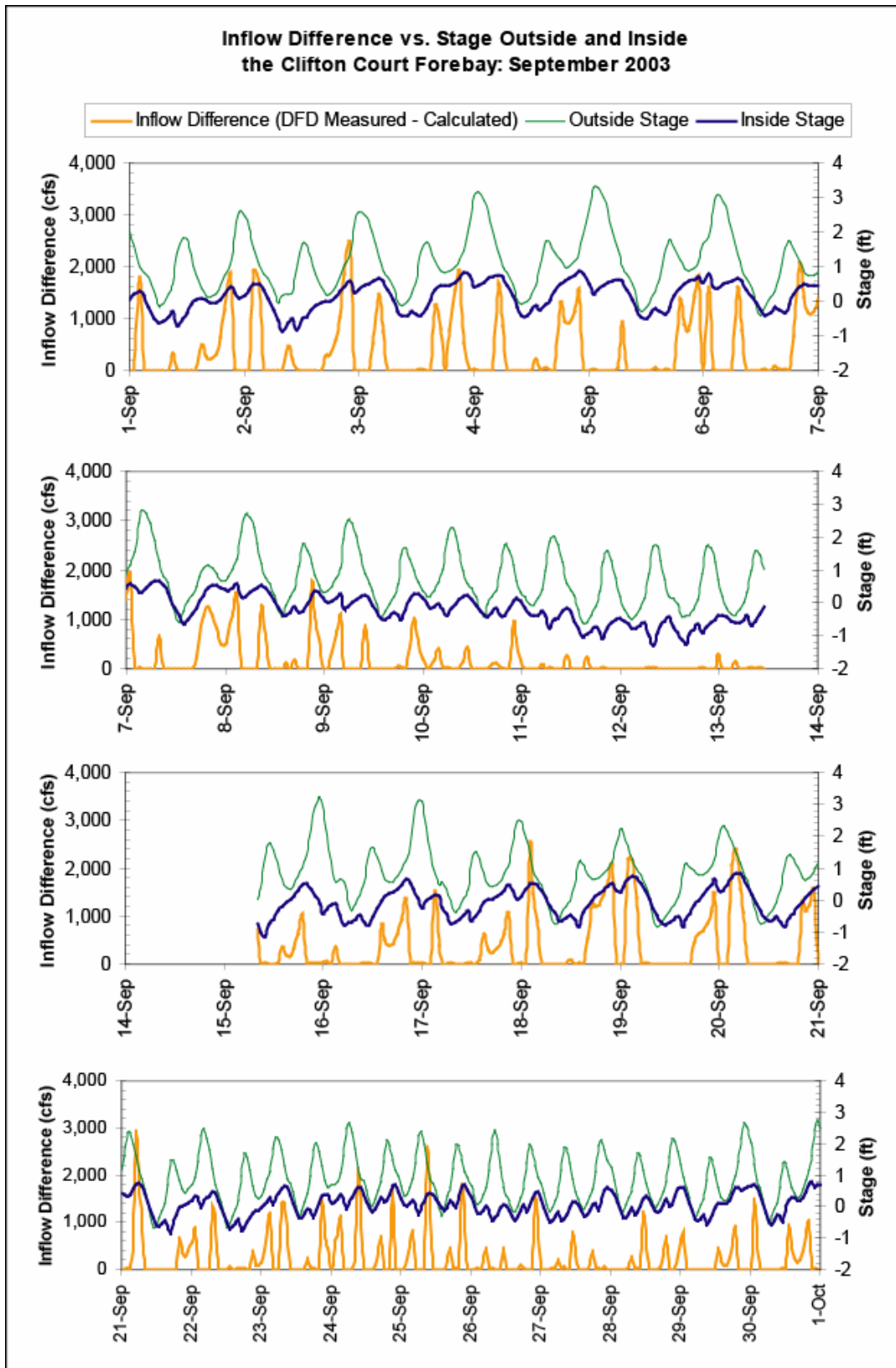
Figure 12.5: Inflow Difference vs. Banks Export: August 2003.
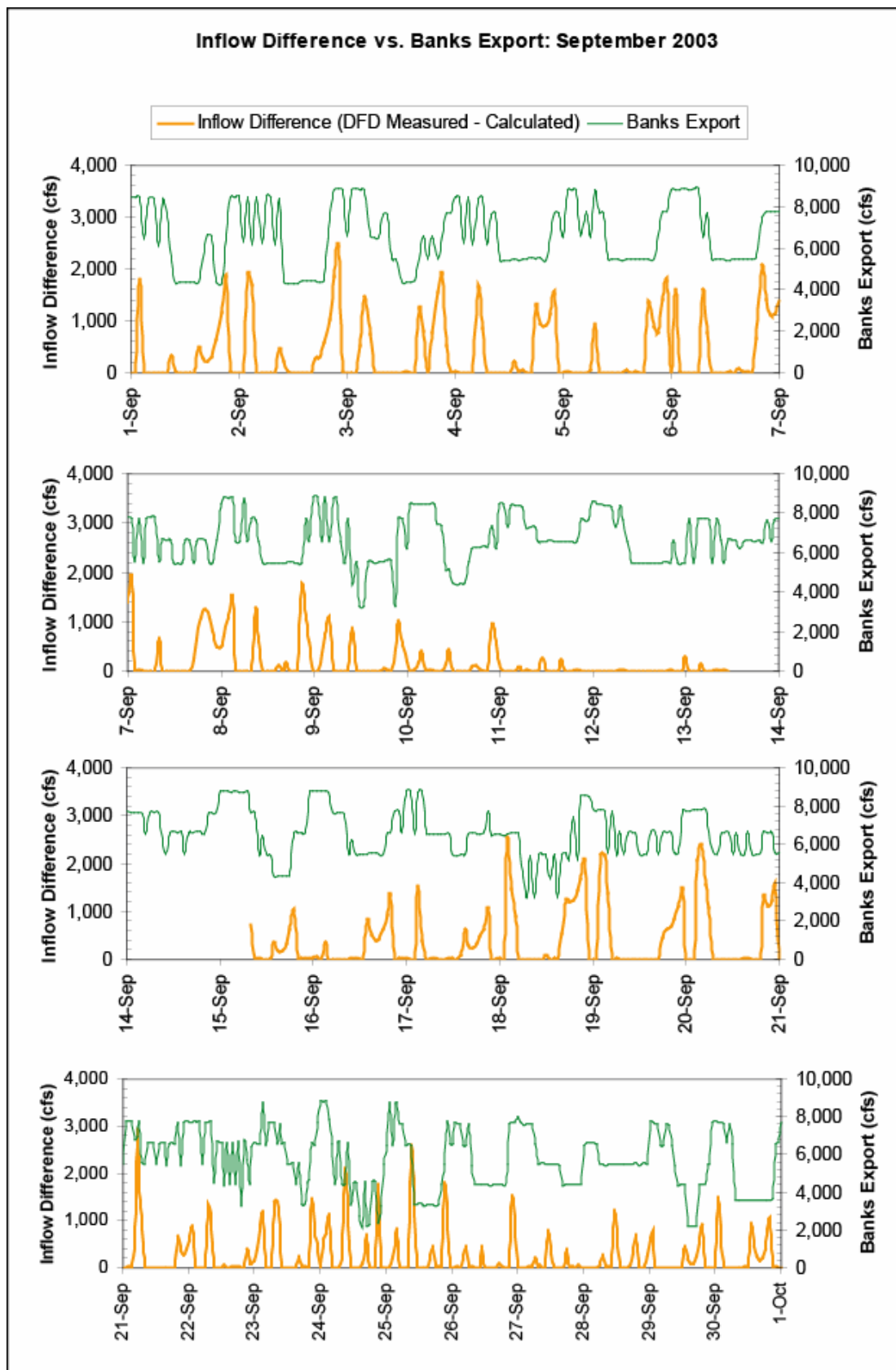
Figure 12.6: Inflow Difference vs. Banks Export: September 2003.
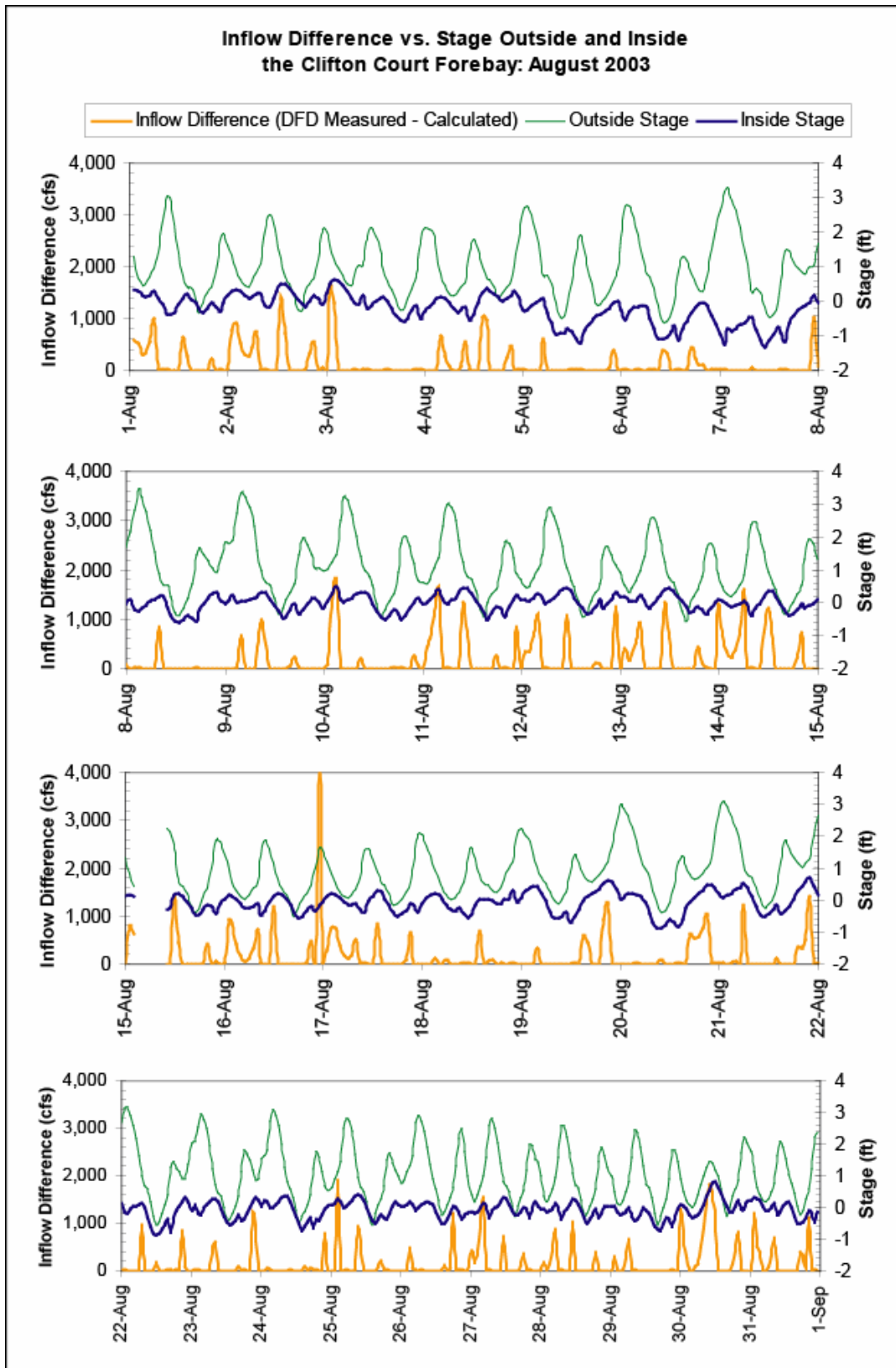
**Figure 12.7: Inflow Difference vs. Stage Outside and Inside
the Clifton Court Forebay: August 2003.**

**Figure 12.8: Inflow Difference vs. Stage Outside and Inside
the Clifton Court Forebay: September 2003.**

The following observations were noted of the plotted results:

❑ The maximum instantaneous flow difference between calculated and measured in August 2003 was 4,292 cfs, but on average the flow difference is 173 cfs as shown in Figure 12.3. It is important to note that the average flow difference includes times when the forebay gates were closed.

❑ The maximum instantaneous flow difference between calculated and measured in September 2003 was 2,919 cfs, but on average the flow difference is 297 cfs as shown in Figure 12.4.

❑ Figures 12.5 and 12.6 indicate no direct correlation between Banks pumping rates with the difference between calculated and measured flow.

❑ Figures 12.7 and 12.8 indicate a relationship between flow difference and stage outside of the intake gates. Most of the flow differences occurred half-way coming into and/or half-way off a high tide.

Monthly averaged data for the period of April through September 2002 were examined. Banks pumping was included to verify if the measured DFD and calculated flow through the forebay gates were valid. The results are shown in Table 12.1. The absolute monthly difference is the difference of the measured from the calculated flows.

Table 12.1: Monthly Averaged Flow Through the Clifton Court Forebay Gates.

Year 2002	Monthly Avg. Banks Pumping	Monthly Avg. Q(calculated)	Monthly Avg. Q(measured)	Absolute Monthly Difference	% Difference
April	2104	2217	2120	96	4
May	625	855	678	177	21
June	2146	2584	2266	318	12
July	6222	6161	6241	80	1
August	n/a	n/a	n/a	n/a	n/a
September	4131	4452	4199	252	6

* Does not include August due to missing data.

12.5 Conclusions

The Clifton Court individual gate equations are the result of Hill's efforts to find a better method to estimate at the gates. DWR's Joint Operations Center added these equations into MS Excel and uses them to estimate the flows into the forebay based on the difference in water levels inside and outside of the forebay. Validations made by Hills (1988) indicate that the tool, offers a quick and consistent method for estimating inflows to the intake gates. The observations of inflow results are as follow:

- ❑ A noticeable pattern was noted that most of the differences between the estimated and field inflows occurred half-way into and half-way out of a high tide.

- ❑ Between August and September of 2003, the largest averaged instantaneous flow difference was 3,605 cfs, but on average the flow difference was 235 cfs.

Though the DSM2-DB (see Chapter 7) will allow accurate modeling of the Clifton Court Forebay Gates, Hills's equations will be useful in recreating the flow through the Clifton Court Forebay Gates.

12.6 Reference

Hills. (1988). *New Flow Equations for Clifton Court Gates*. Technical Memorandum. California Department of Water Resources, State Water Project Division of Operations and Maintenance. Sacramento, CA.

12.7 Website

An example of the MS Excel Spreadsheet used by the Department is available in the Reports section at:

http://iep/dsm2pwt/dsm2pwt.html

Download the *Clifton Court Inflow Spreadsheet*.

Acronyms and Abbreviations

1D – 1-dimensional

2D – 2-dimensional

3D – 3-dimensional

ATT – Adjusted Astronomical Tide

ADICU – Adjusted Delta Island Consumptive
Use

AMR – Adaptive Mesh Refinement

ANN – Artificial Neural Network

BOD – Biochemical Oxygen Demand

BBID – Byron Bethany Irrigation District

CALSIM – California Water Resources
Simulation Model

CALSIM II – California Water Resources
Simulation Model II

CCF – Clifton Court Forebay

CCWD – Contra Costa Water District

CVP – Central Valley Project (also Tracy
Pumping Plant)

cfs – cubic feet per second

DAYFLOW – computer program used to
calculate Delta boundary hydrology

DCC – Delta Cross Channel

DFD – DWR Delta Field Division

DICU – Delta Island Consumptive Use Model

DMC – Delta Mendota Canal

DHQ – Diurnal High Water Inequality

DLQ – Diurnal Low Water Inequality

DTL – Diurnal Tidal Level

DO – Dissolved Oxygen

DOC – Dissolved Organic Carbon

DSM2 – Delta Simulation Model 2

DSM2-DB – Delta Simulation Model 2 Database
version

DWR – California Department of Water
Resources

DWSC – San Joaquin River Stockton Deep
Water Ship Channel

EC – Electrical Conductivity

EIR/EIS -- Environmental Impact Report /
Environmental Impact Statement

FAQ – Frequently Asked Questions

GB – Gigabyte

GHz – Gigahertz

GIS – Geographic Information System

GLC – Grant Line Canal

Gt – Great Diurnal Range

GUI – Graphical User Interface

HDF5 – file format for saving data

HYDRO – DSM2 Hydrodynamics Model

IEP – Interagency Ecological Program

ISI – Integrated Storage Investigation (part of
DWR)

IDS – ISI In-Delta Storage Program

LAN – Local Area Network

LBNL – Lawrence Berkeley National
Laboratories

LVR – Los Vaqueros Reservoir intake

MHHW – Mean Higher High Water

MHW -- Mean High Water

MLLW – Mean Lower Low Water

MLW – Mean Low Water

Mn – Mean Range

MSL – Mean Sea Level

MTL – Mean Tide Level

MWD – Metropolitan Water District of Southern
California

MWQI – Municipal Water Quality
  Investigations
NAVD88 – North American Vertical Datum of
  1998
NDO – Net Delta Outflow
NDOI – Net Delta Outflow Index
NOAA – National Oceanic and Atmospheric
  Administration
O&M – DWR Operations and Maintenance
OWQ – DWR Division of Environmental
  Service's Office of Water Quality
PTM – DSM2 Particle Tracking Model
PWT – DSM2 Project Work Team
QA/QC – Quality Assurance / Quality Control
QUAL – DSM2 Water Quality Model
QUAL2E – Enhanced Stream Water Quality
  Model
REALM – River, Estuary, and Land Model
RMA2 – multi-dimensional hydrodynamic and
  water quality finite element model
RMA Tools – DWR's RMA2 postprocessor
RS – Rock Slough intake
RTDF – Real-Time Data and Forecasting
RWCF – City of Stockton's Regional
  Wastewater Control Facility
SJR – San Joaquin River
SQL – Structured Query Language
SWP – State Water Project
TDS – Total Dissolved Solids
TMDL – Total Maximum Daily Load
USBR – U.S. Bureau of Reclamation
USGS – U.S. Geological Survey
UVM – Ultrasonic Velocity Meter
VAMP – Vernalis Adaptive Management Plan
WQMP – D-1643 Water Quality Management
  Plan

WRESTL – programming language used in
  CALSIM